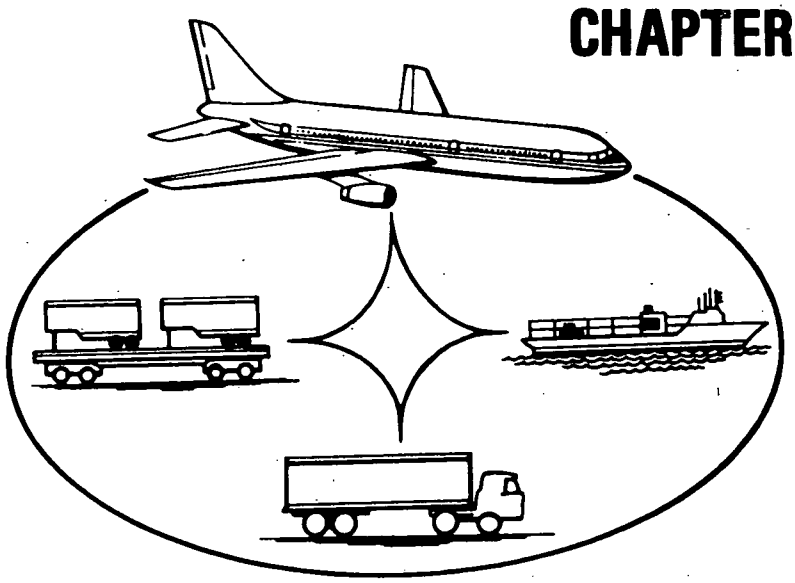
CHAPTER 1



NETWORK DESIGN

CHAPTER 1

NETWORK DESIGN

Introduction

A transportation network consists of areas to be served, nodal points, and connecting lines between nodes.

An efficient network seeks to equalize service areas which should result in more equal user cost throughout the system. Nodal points of this system are airports and air terminals that, ideally, are capable of providing the service called for by the service areas. Connecting lines are the routes that connect nodal points to each other and to major hubs that serve as collection points for whole countries or continents, depending upon size. Connecting lines are further modified by frequency of use and balance of flow in both directions of each link. Finally, the type of aircraft that fly the connecting routes are part of the network and should be suited to the length of lines and density of flow as well as being efficient to load, fly, and unload.

In what follows, node location is treated first from theoretical implications derived from central place theory (ref. 7). This is followed by a pragmatic treatment of the closely associated problems of routing and scheduling in Section 1.2. The routing (connectivity design) and scheduling discussion is prefaced by a description of the needs of the shipper relative to routing and scheduling. The discussion of routing and scheduling is followed by a discussion of network economics in Section 1.3. This, in turn, is followed by a discussion of cargo handling capacities and potential at existing airports in Section 1.4, by the implications of intermodal transfer upon network design in Section 1.5, and finally by the closely allied problems of aircraft payload and fleet-size in Section 1.6.

1.1 THE NETWORK

1.1.1. Theoretical Design of Network

The ideal air cargo transportation network has as its goal the economic transportation of all air-eligible cargo in the United States; it also is to provide links, gateways as it were, with an international network comprising the major continents of the world.

The collection point of all goods that need to be transported by air should be located in the center of a circular area. This same center, of course, can also serve as the final distribution point from which all goods are delivered, at equal cost, in all directions to the final destination within any service area (Fig. 1.1).

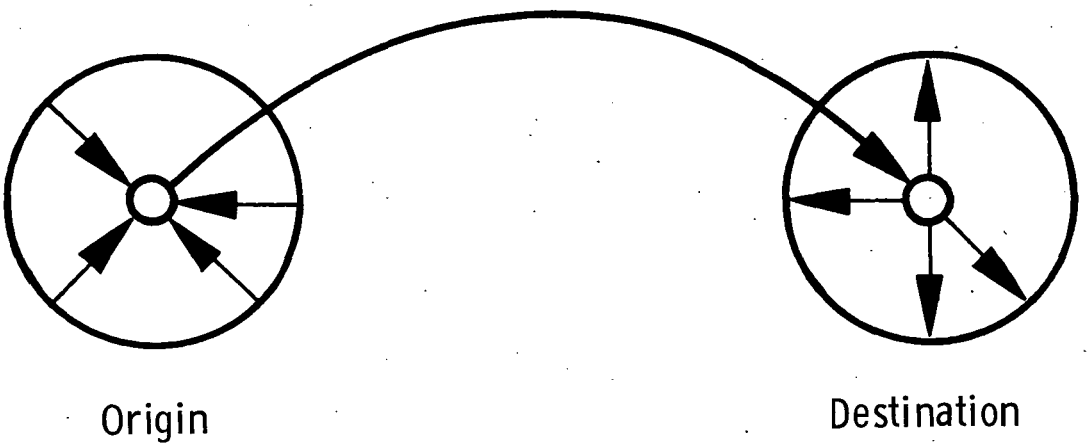


Figure 1.1 ORIGIN AND DESTINATION

The energy required to transport all goods to or from the center is as uniform as the terrain within the area. However, a series of tangent circles that cover all available space would leave unserviced areas between them (Fig. 1.2). Hence, for total service, the circles should overlap and divide the space between them, producing a system of nesting hexagons. Hexagons represent the optimum compromise to circles. They have the advantage of covering all space that needs to be serviced (Fig. 1.3).

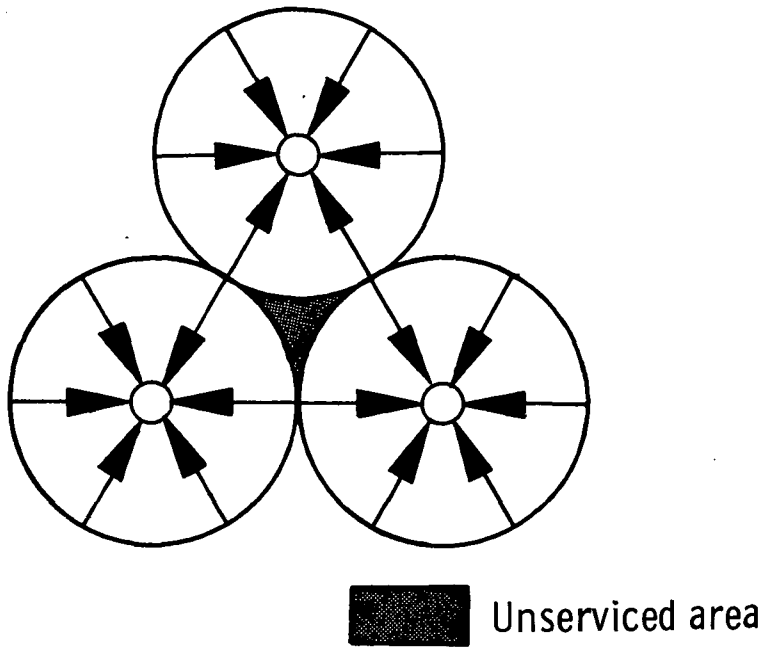


Figure 1.2 UNSERVICED AREAS

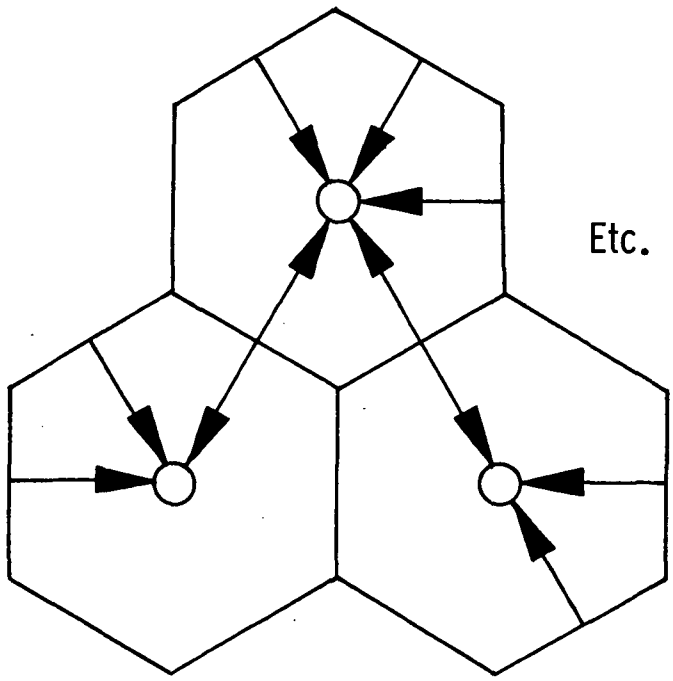


Figure 1.3 HEXAGONAL SERVICE AREAS

The hexagon pattern applied to the continental United States represents the lowest order of the network hierarchy of areas; this area is intended to be serviced primarily by surface transportation modes (Fig. 1.4). There is no distance within any hexagon that exceeds 800km (500 miles) to a central place for collection of cargo.

Distances between hexagon centers are closer to 1000km (600mi) which represent distance minima where air transportation by medium sized, intermediate distance aircraft can compete in time and cost with rail or truck. These distances represent the next larger hierarchy of hexagons (Fig. 1.5). It is here that the domestic air cargo industry will make major inroads in the surface transportation modes. The economics of the competition can be seen from Figure 1.6 and Figure 1.7, especially between trucks and long haul aircraft.

The continents as service areas represent the largest of the three sets of hexagons. The theoretical nesting of Figure 1.8 is merely to illustrate that all land masses can be serviced without gaps. Even if Asia and Australia were to be separated, as in Figure 1.9 (in order to come closer to the reality of distribution of continents), the interesting observation can be made that the distances between continents are fairly uniform (Table 1.1). The importance of this fact is that the technology exists to link continents in an air transportation network of fairly uniform service areas and distances. Aircraft like the B-747 or the C-5 are now in service over such distances (Table 1.2). Of course, countries like the Soviet Union and the United States have distances within their national boundaries (Table 1.1) that approach intercontinental distances and a detailed map would tend to show more than one super hub.

The hierarchical arrangement of service areas has the advantage of making available to the shipper economy of scale: The larger the distance to be shipped in any one haul, the lower the unit cost of goods shipped by any given mode. As a corollary to this principle, the larger the carrier, the lower the unit cost of a good shipped. The larger aircraft can negotiate the longer hauls and, hence, reduce unit cost. Both the United States and the Soviet Union can avail themselves of the largest aircraft over very long hauls and thereby lower the unit cost of goods transported within their boundaries. Over such distances, the time-cost advantage of the long air haul combined with reduced inventory and storage needs tend to equalize direct operating costs (DOC) between air mode and overland transportation (Figs. 1.6 and 1.7). Transportation of a single container over a very short distance by, say, helicopter will be costly; only extreme time pressure in a congested urban center around a given airport would warrant such an expense.

Central places in a mixed hierarchy represent an equilibrium of "least work" in an energy flow system (ref. 1). Central places are concentrations of human beings and their activities in any location ranging from villages, to towns, to cities, all the way to metropolitan areas. The term "mixed" refers to organization of space according to market areas, transportation routes, and economy of size in a complex social economic society. The mixed hierarchy here represented combines the market areas, wherein goods are collected primarily by surface transportation, with a transportation hierarchy of larger central places, and active airports, connected by direct air service with each

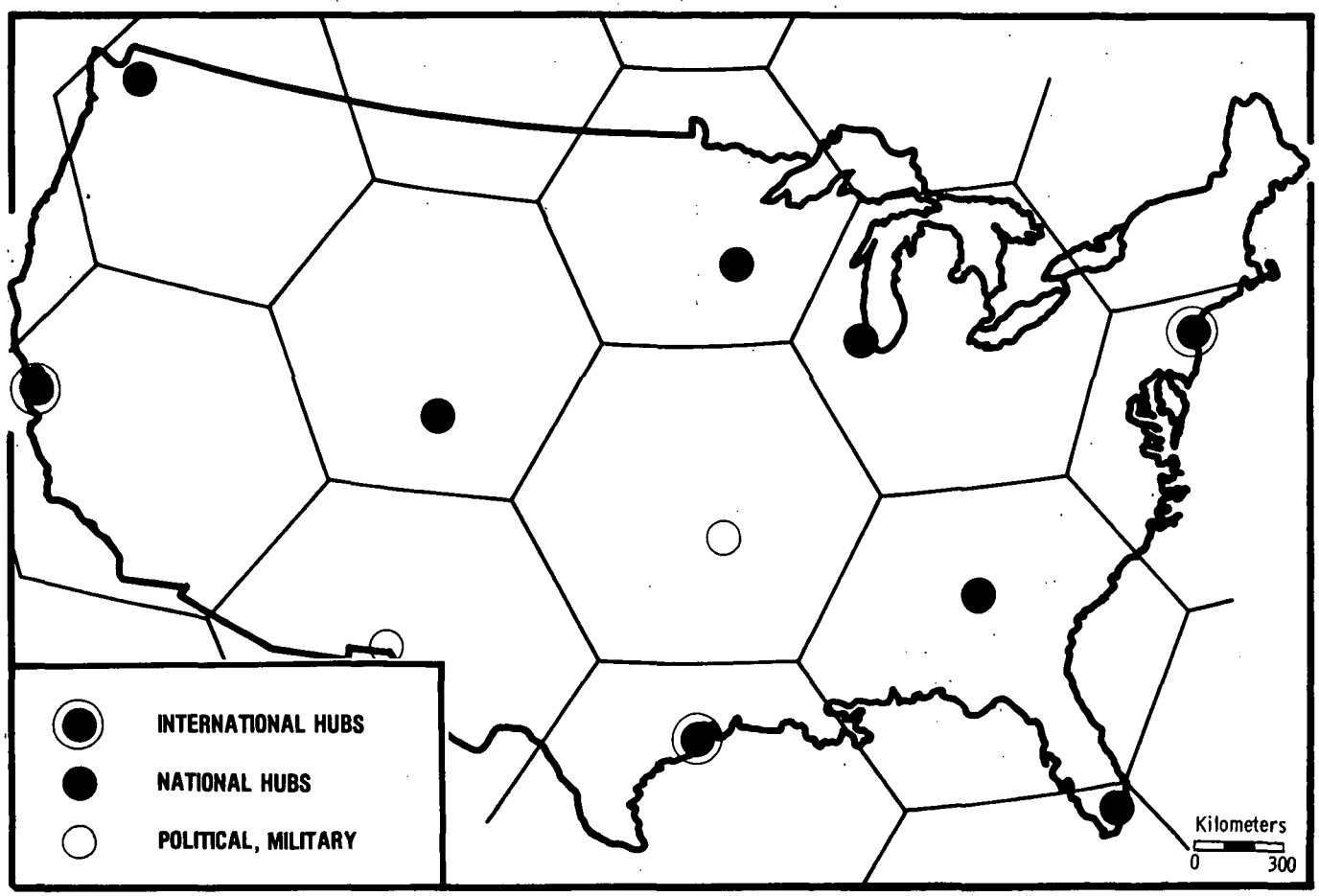


Figure 1.4 AIR CARGO NETWORK AND SERVICE AREAS

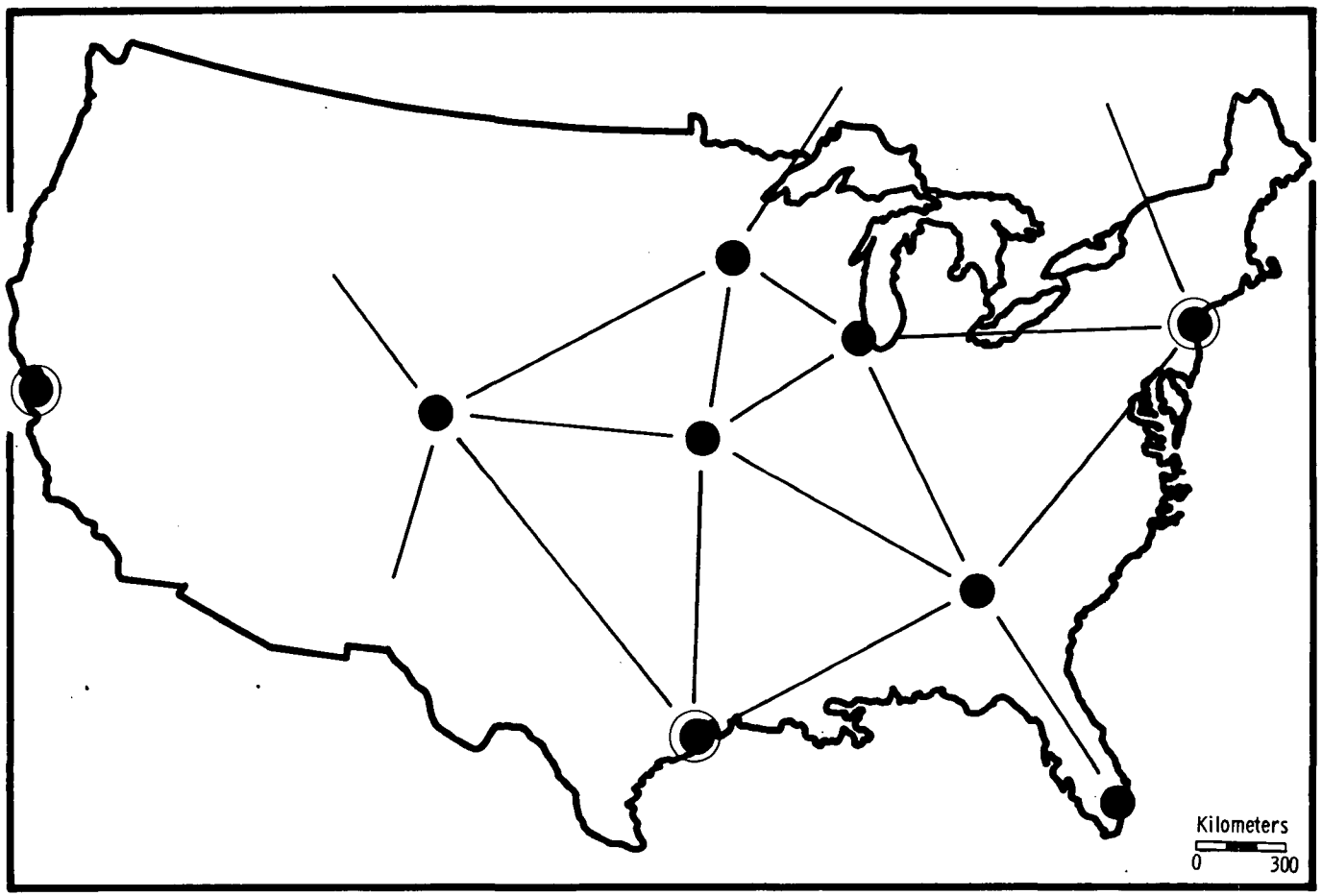


Figure 1.5 SECOND ORDER HIERARCHY

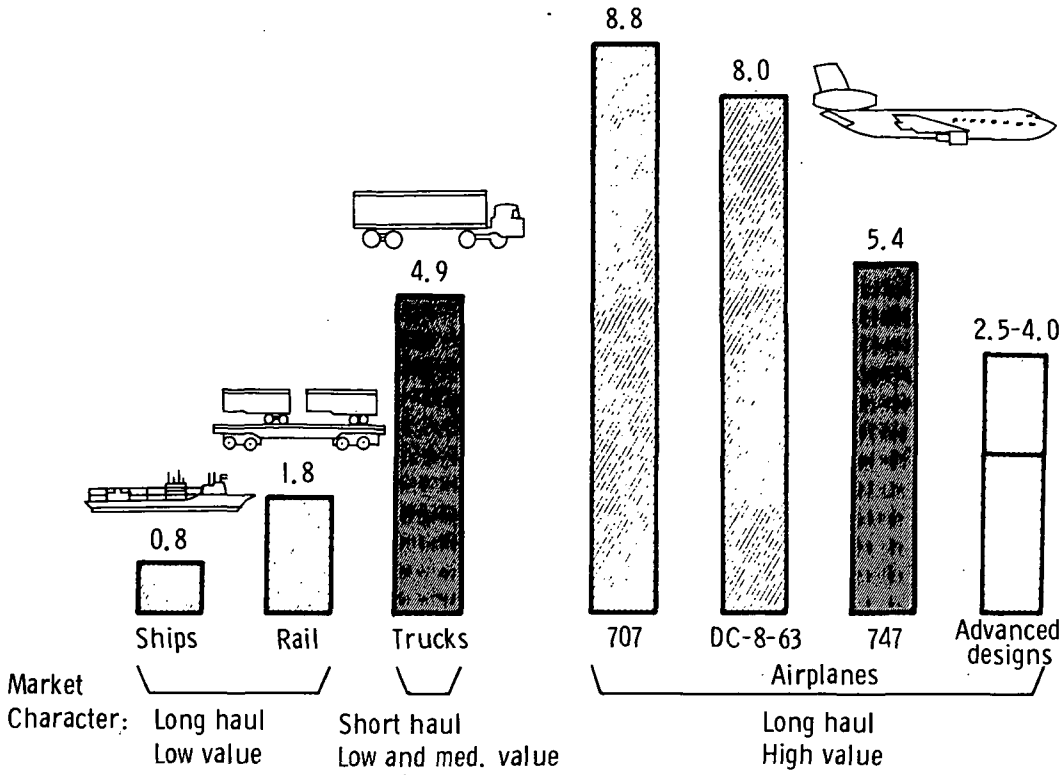


Figure 1.6 TRANSPORTATION COST IN CENT PER TON-MILE (Source: The Russellville Concept, An Intermodal Cargo Transportation System, Russellville, Arkansas, February 1978, p. 47).

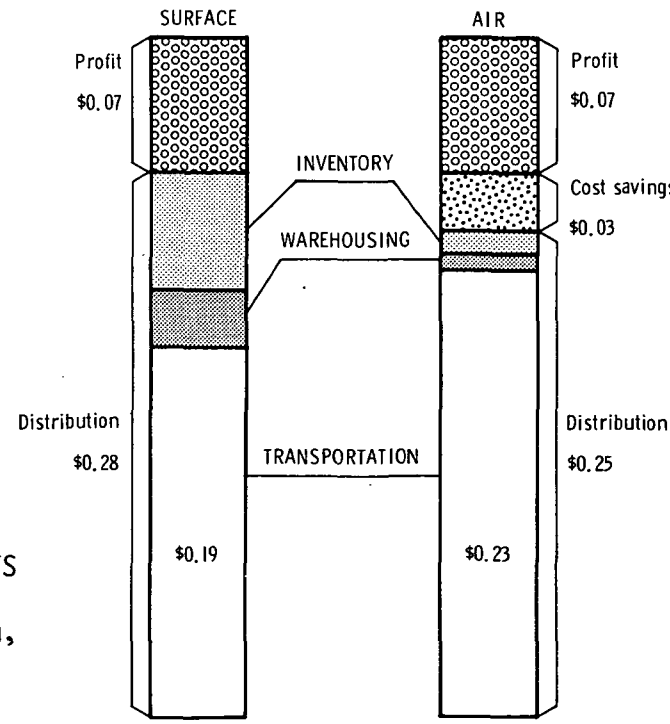


Figure 1.7

THE CONCEPT OF TOTAL DISTRIBUTION COSTS (Source: The Russellville Concept; An Intermodal Cargo Transportation System, Russellville, Arkansas, February 1978, p. 43).

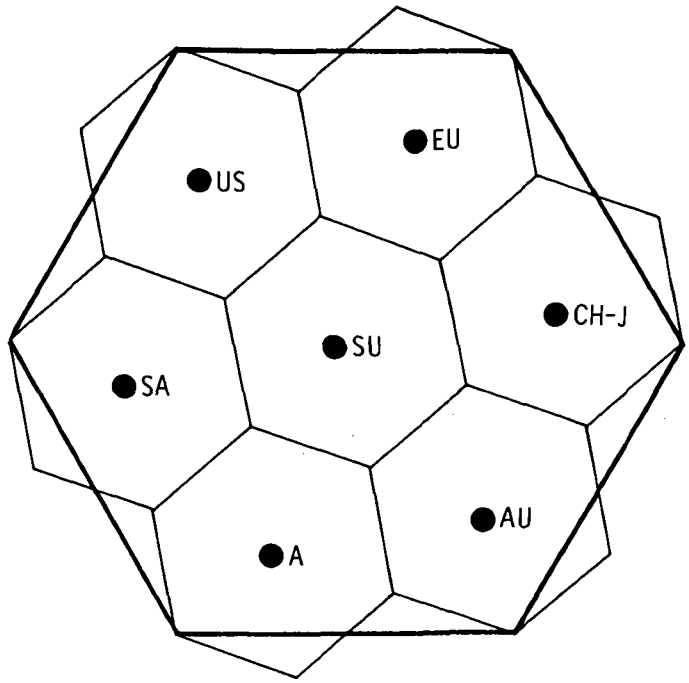


Figure 1.8 WORLD SERVICE AREAS

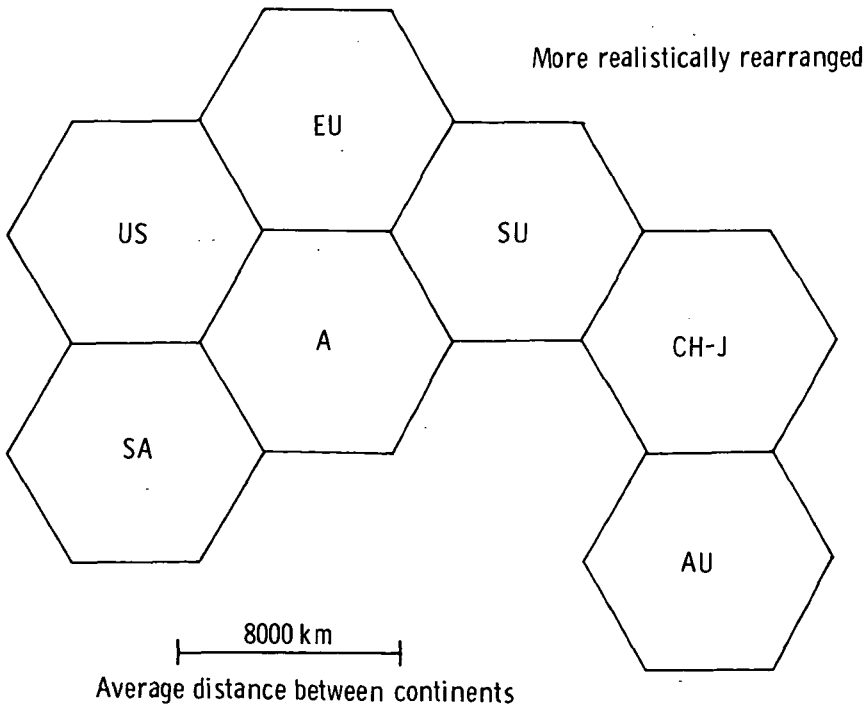


Figure 1.9 WORLD SERVICE AREAS (MORE REALISTICALLY REARRANGED)

Table 1.1

TYPICAL DISTANCES AND AVERAGES

	Miles	Kilometers
North Atlantic	4460	7178
North Pacific	6370*	10,252
North - South America	5320	8562
U.S. - Middle East & Africa	7000*	11,265
Europe - Far East/Australia	10,500*	16,898
Europe - Africa	3300	5311
Europe - Middle East	2500	4023
Europe - L/Developed America	5300	8530
Japan - L/Dev. Far East & Australia	2500	4023
Japan - Africa & Middle East	8000*	12,875
Japan - L/Developed America	11,000*	17,703
Average distance	4140	8926

*usually two stops; see below

U.S. - Australia		
Los Angeles - Honolulu - Sydney	2556,5067	4729,9376
New York - Honolulu - Sydney	4893,5067	9220,9376.
U.S. - Africa		
New York - Dakar - Nairobi	3805,1498	7041,2722
Kinshasa - Lisbon - New York	3360,3367	6217,6230
U.S. - Asia		
Los Angeles - Honolulu - Tokyo	2556,3854	4279,7131
New York - Fairbanks - Tokyo	3278,3522	6065,6517

Table 1.2

AIRPORTS IN U.S. AND CANADA WITH B-747 SERVICE, 1978 (Ref. 46)

Airport	No. Airlines flying B-747	No. Airlines flying B-747 F/C*	No. Airlines Serving Airport
J.F. Kennedy (NYC)	18	5	72
O'Hare (ORD)	9	3	47
Los Angeles (LAX)	7	0	43
San Francisco (SFO)	7	0	33
Honolulu (HNL)	7	0	24
Boston (BOS)	5	2	36
Toronto (YYZ)	5	1	22
Seattle-Tacoma (SEA)	4	2	21
Mirabel (Montreal) (YMX)	4	2	23
Dulles (IAS)	4	0	16
Detroit Metro (DTW)	3	0	28
Anchorage (ANC)	3	1	18
Miami (MIA)	2	0	54
Houston (IAD)	2	1	22
Las Vegas (LAS)	2	0	15
Vancouver (YVR)	2	0	9
Hilo (ITO)	2	0	8
Dallas-Ft. Worth (DFW)	1	0	23
Denver (DEN)	1	0	27
Philadelphia (PHL)	1	1	20
Minneapolis-St. Paul (MSP)	1	1	20
St. Louis (STL)	1	0	22
Pittsburg (PIT)	1	0	14
Phoenix (PHX)	1	0	10
Montreal Int'l. (YUL)	1	0	14
Milwaukee (MKE)	1	1	11

*The B-747F and B-747C are coded as a separate category in ref. 46 as all-freight versions with nose loading main deck. Column 3 numbers are included in the numbers listed in Column 2, though the same airline may fly both all-cargo and belly 747's.

other. Each continent can be considered as having one large "hub" airport that is connected with lower order airports as if by "spokes". Such a system is referred to as a "hub-spoke" system, indicating a hierarchy of areas and services.

1.1.2. "Fitting" Central Place Theory to the Reality of the American Landscape

A glance at Figure 1.4 will show that the hexagonal service areas covering the contiguous United States are fairly equal but the transportation collection points are not always in the centers. The specific choice of centers was influenced by the intention to utilize existing facilities and technology as much as possible. Another aspect of reality that will tend to distort the theoretical lattice is that the area of a service circle, in this case a hexagon, of either a hub or a spoke terminal will tend to be proportional to the amount of cargo traffic generated within it (ref. 2). In other words, sparsely settled areas tend to have larger spatial service areas than densely settled areas, even though they may be "equal" in total service.

All of the terminal hubs selected have runways that can accommodate large aircraft like the B-747 (ref. 3); the preferred width is 61m (200ft) although 45m (150ft) will also do (Also compare Table 1.2).

Seattle, San Francisco, and Los Angeles are located in the western part of their hexagonal service areas, as is Chicago. This location corresponds to the reality of commercial, industrial, and demographic distribution of human activity. Thus, these cities are more properly placed in the "activity centers" of their respective areas.

Miami appears to preside over an area that is mostly water. However, Miami ranks rather high in a hierarchy of airport activity (Table 1.3), activity that is generated by its "central" location with respect to the active Caribbean area which Miami serves.

San Francisco, Houston, and New York serve the dual functions of collecting points for their respective hexagons as well as points of entry and departure for longhaul international cargos.

Finally, hexagons that center on El Paso, Texas, and Emporia, Kansas, might be good examples of two other considerations of "reality" that also influence the specific location of central places of a given network:

1. Political considerations, and

2. National defense considerations.

Russellville, Arkansas, has been selected as an example of the political process at work as it contributes to the industrial and economic evolution of the cultural landscape (ref. 4). There are other suggestions for the establishment of similar all-cargo freightports in Coalinga, California, the Pacific International Freeport Center near Ogden, Utah, as well as the International Air Cargo Distribution Project planned for Northwestern Nevada: "in the

Table 1.3

FORTY LARGER AMERICAN AIRPORTS AND THE NUMBER OF CERTIFIED CARRIERS SERVING THEM, RANKED BY FREIGHT ENPLANED, 1977

F	AL	AF	AIRPORT	FT	DP	F/P	Pax	P
1	47	78	Chicago (ORD)	366	293	2500	19.2	1
2	72	112	N.Y.-J.F. Kennedy (NYC)	365	108	6800	7.7	5
3	43	87	Los Angeles (LAX)	335	145	4600	10.9	3
4	33	64	San Francisco (SFO)	192	101	3800	7.0	8
5	21	26	Seattle-Tacoma (SEA)	143	56	5100	3.6	20
6	54	54	Miami (MIA)	134	84	3200	5.2	12
7	22	21	Atlanta (ATL)	132	221	1200	15.0	2
8	28	32	Detroit (DET)	104	81	2550	4.3	13
9	23	32	Dallas-Ft. Worth (DFW)	94	148	1250	8.4	4
10	24	16	Honolulu (HNL)	89	47	3800	5.3	11
11	36	38	Boston (BOS)	81	100	1600	5.7	10
12	27	17	Denver (DEN)	63	122	1050	7.1	7
13	20	28	Philadelphia (PHL)	53	69	1550	3.7	18
14	18	21	Cleveland (CLE)	49	51	1990	3.1	22
15	20	14	Minneapolis-St. Paul (MSP)	47	68	1400	3.8	16
16	20	36	Newark (EWR)	43	65	1300	3.6	19
17	22	42	Houston (IAH)	41	68	1200	3.8	17
18	22	19	St. Louis (STL)	29	90	650	4.1	15
19	20	10	N.Y.-La Guardia (LGA)	27	132	400	7.6	6
20	15	26	Baltimore-Washington (BAL)	23	63***	750	1.5	*
21	14	12	Pittsburgh (PIT)	20	92	450	4.2	14
22	18	19	Washington National (DCA)	18	105	350	6.2	9
23	15	16	New Orleans (MSY)	17	47	700	2.7	23
24	20	8	Tampa (TPA)	15	58	500	2.6	24
25	10	10	Phoenix (PNX)	14	48	600	2.5	25
26	15	0	Las Vegas (LAS)	3	52	100	3.5	21
*	18	9	Anchorage (ANC)	**	**	**	**	*
*	13	11	Charlotte (CLT)	**	**	**	**	*
*	13	13	Cincinnati (CIN)	**	**	**	**	*
*	16	0	Dulles (IAD)	**	**	**	**	*
*	14	1	Fort Lauderdale	**	**	**	**	*
*	14	15	Kansas City (MCI)	**	**	**	**	*
*	16	12	Memphis (MEM)	**	**	**	**	*
*	14	8	Montreal-Int'l (YUL)	**	**	**	**	*
*	23	8	Montreal-Mirabel (YMX)	**	**	**	**	*
*	15	5	Nashville (BNA)	**	**	**	**	*
*	14	15	Portland (PDX)	**	**	**	**	*
*	12	11	Salt Lake City (SLC)	**	**	**	**	*
*	14	16	San Diego (SAN)	**	**	**	**	*
*	22	10	Toronto (YYZ)	**	**	**	**	*

* Not ranked in the top 26 ** Data not available *** Half of flight movement

evolution of transportation decision making . . . . economic importance (will) decline in relative importance as decisions become more politicalized" (ref. 5).

The establishment of a totally new all-cargo air terminal at Russellville was conceived by a group of businessmen and industrial leaders. They proceeded to enlist senators and congressmen in their effort to build political support for establishing a dedicated all-cargo, fully intermodal air terminal in their town. Figure 1.10 illustrates the major "modes" of transportation and the "link" between them, namely the standard container, 2.44m x 2.44m x 3.05m or 6.10m or 12.19m (8ft x 8ft x 10ft or 20ft or 40ft).

It is not certain whether the Russellville group will succeed in their attempt; nevertheless, political clout and pull will have some effect upon the location of modern airports as will such other factors as commercial activity, links to other transportation modes, and available land. The same will be true with the exact location of a modern dedicated gateway freightport, now called "New York" which will serve the megalopolis "BosWash" (the congested urban landscape from Boston to Washington), and whether Dallas will get the nod over Houston, or San Francisco over Los Angeles.

There is an established commercial airport in the vicinity of El Paso, Texas, but not of the order of magnitude as shown on Figure 1.15. The hexagonal grid indicates that an airport should be developed in that vicinity, if for no other reason than strategic considerations. However, there appears to be an adequate air force base in the area, Holloman Air Force Base, which could also be converted to civilian use, thus serving as a model for civilian/military cooperation in the development of a total air cargo system.

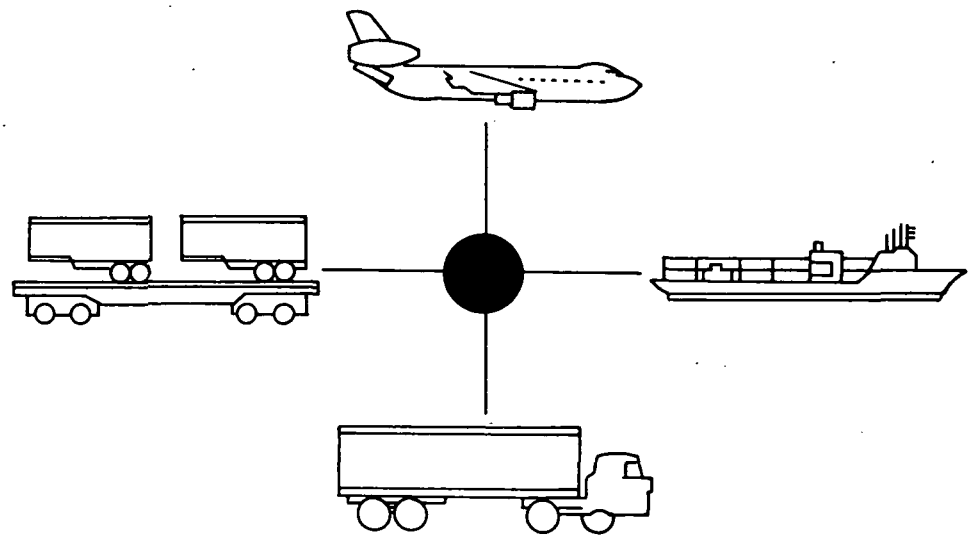


Figure 1.10 THE INTERMODAL AIR CARGO TERMINAL CONCEPT

Such a jointly used air terminal could give rise to the rules and regulations, security measures and civil freedom of action, training of crews for CRAF, and other measures needed in national emergencies.

The FAA 1976 National Aviation System Plan estimates that the total number of airports in the system will grow from 3290 in 1975 to 4066 in 1990 for publicly used and jointly used civil/military airports within the U.S. and its territories (ref. 6), "where there is a national interest in providing reasonable access to the nation's air transportation system".

1.1.3 The Relation of the Designated Centers to Other Modes of Transportation

The locations of most of the airports in or near the centers of the hexagons have developed naturally in conjunction with nearby interstate highways and major trunk railroads. The basic reason, of course, is that urban concentrations developed historically in response to fertile land and favorable communication corridors (Figs. 1.11, 1.12, and 1.13).

As can be seen from these maps based on Department of Transportation published maps and one sketch map, the suggested air terminals of the system are astride the major flow of goods in the U.S. Between them, these airports also handle the major air cargo flows as shown on the percentage distribution map of air freight activity at major U.S. domestic airports, for 1976 (Fig. 1.14). Boston, New York, Philadelphia, and Washington will be served by the new airport to be built, called New York in the proposed network.

1.1.4 The Location of New, Dedicated Major Hub "Gateways"

San Francisco, New York, and Houston have been designated as "gateways" to the international network because of their location with respect to Europe, Africa, South America, and the Orient. The intent is to create entirely new and dedicated cargo-only freightports that have easy access to all other major modes of transportation, i.e., rail, highway, and water. These freightports will have to be located away from present urban surface and air lane congestion as none of the existing major airports in the areas concerned will be able to absorb the expected increase in container cargo anticipated for the 1990-2015 target period envisaged for this system (See Figure 1.15 for anticipated growth in air activity in 1990).

In view of the fact that approximately 50% of all cargo in 1990 will continue to be carried as "belly" cargo both in passenger craft and in dedicated cargo planes, albeit in standardized containers, some provision has to be made to link the freightports with existing mixed passenger and cargo terminals for hub-spoke transfer of containers in either direction. Such links could be fully automated rail links (like the San Francisco BART System) or very limited access roads between the airports for special rubber wheeled trains or trucks. The federal government favors the planning of land for new, large airports. According to an act, signed by President Ford July 12, 1976, the Federal Government will participate in 75%-90% of the cost of purchasing land interests to insure that neighboring land use is compatible with airport operations (ref. 6).

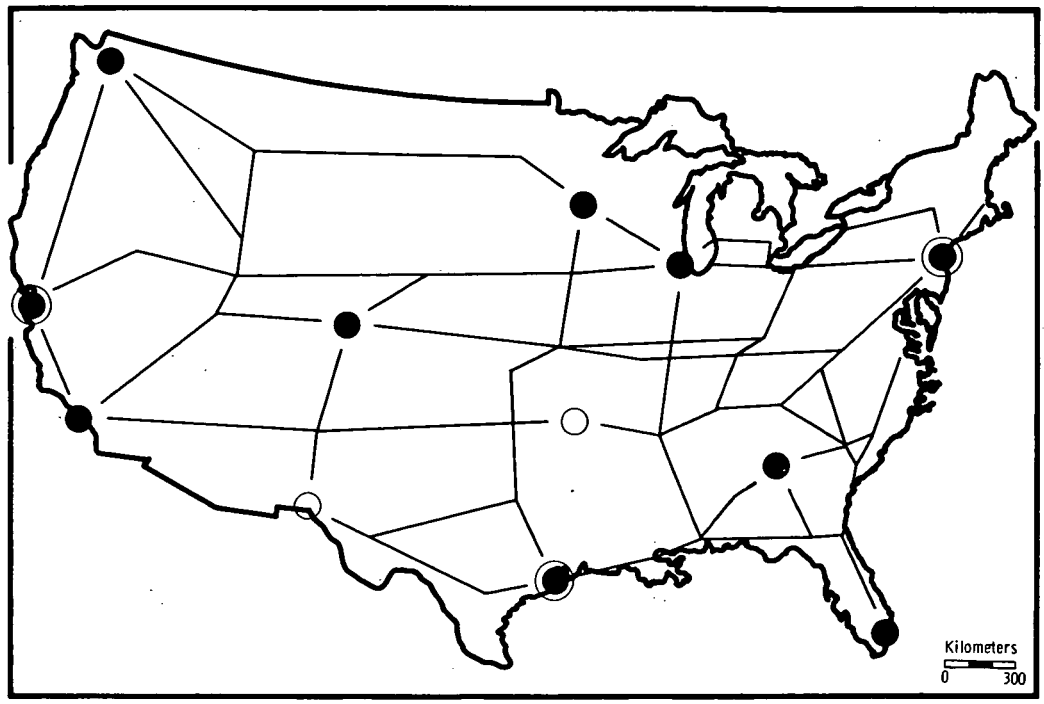


Figure 1.11 INTERSTATE HIGHWAYS (Ref. 6)

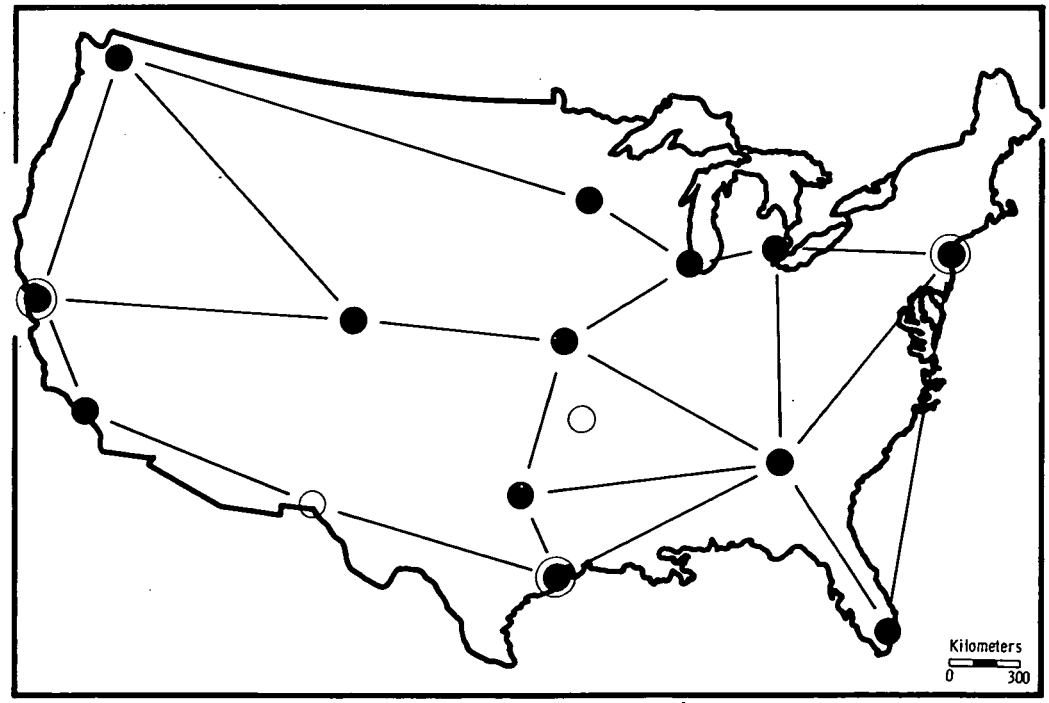


Figure 1.12 CLASS A OR POTENTIAL RAILWAYS (Ref. 6)

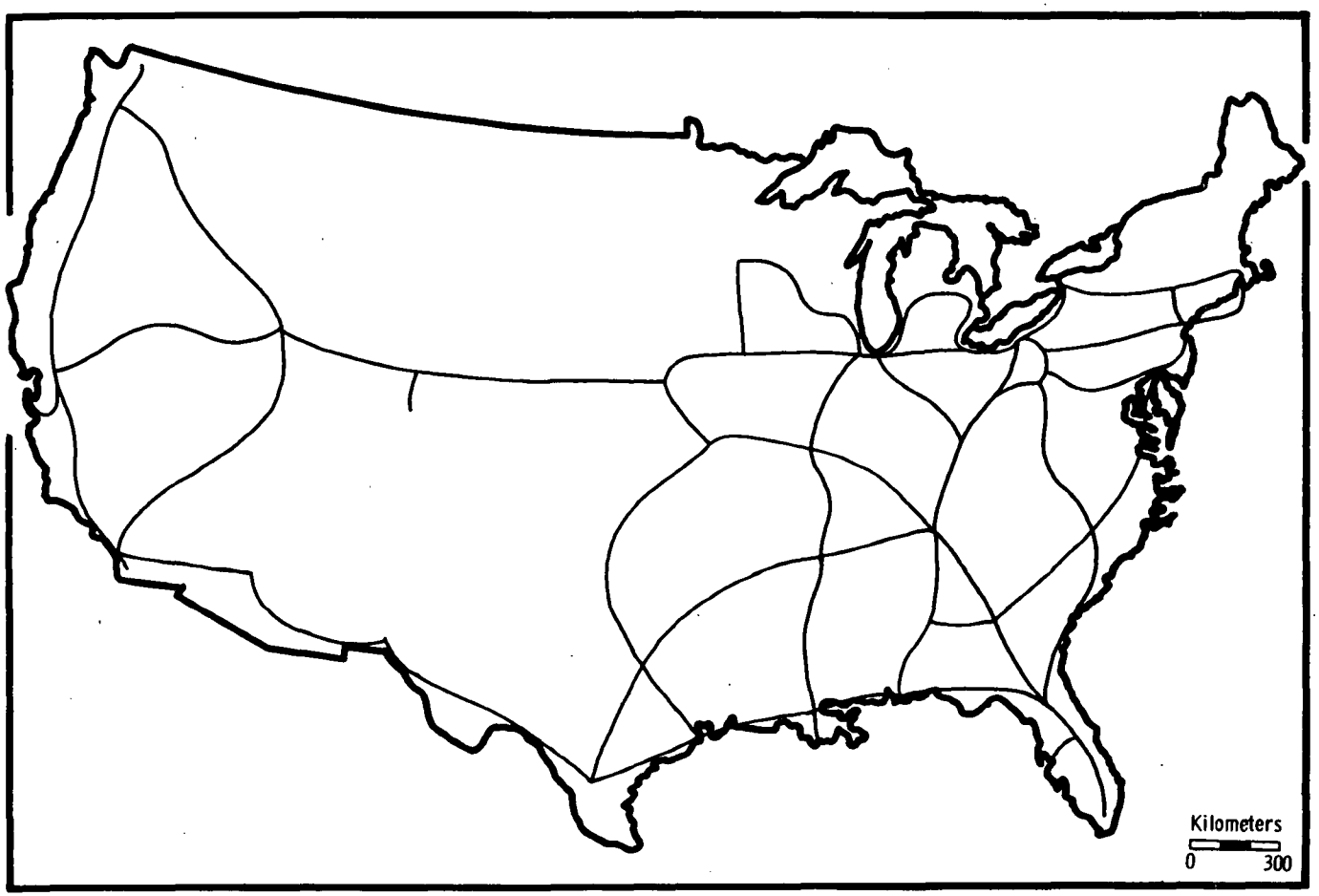


Figure 1.13 INTERMODAL NETWORK (RAIL & ROAD)

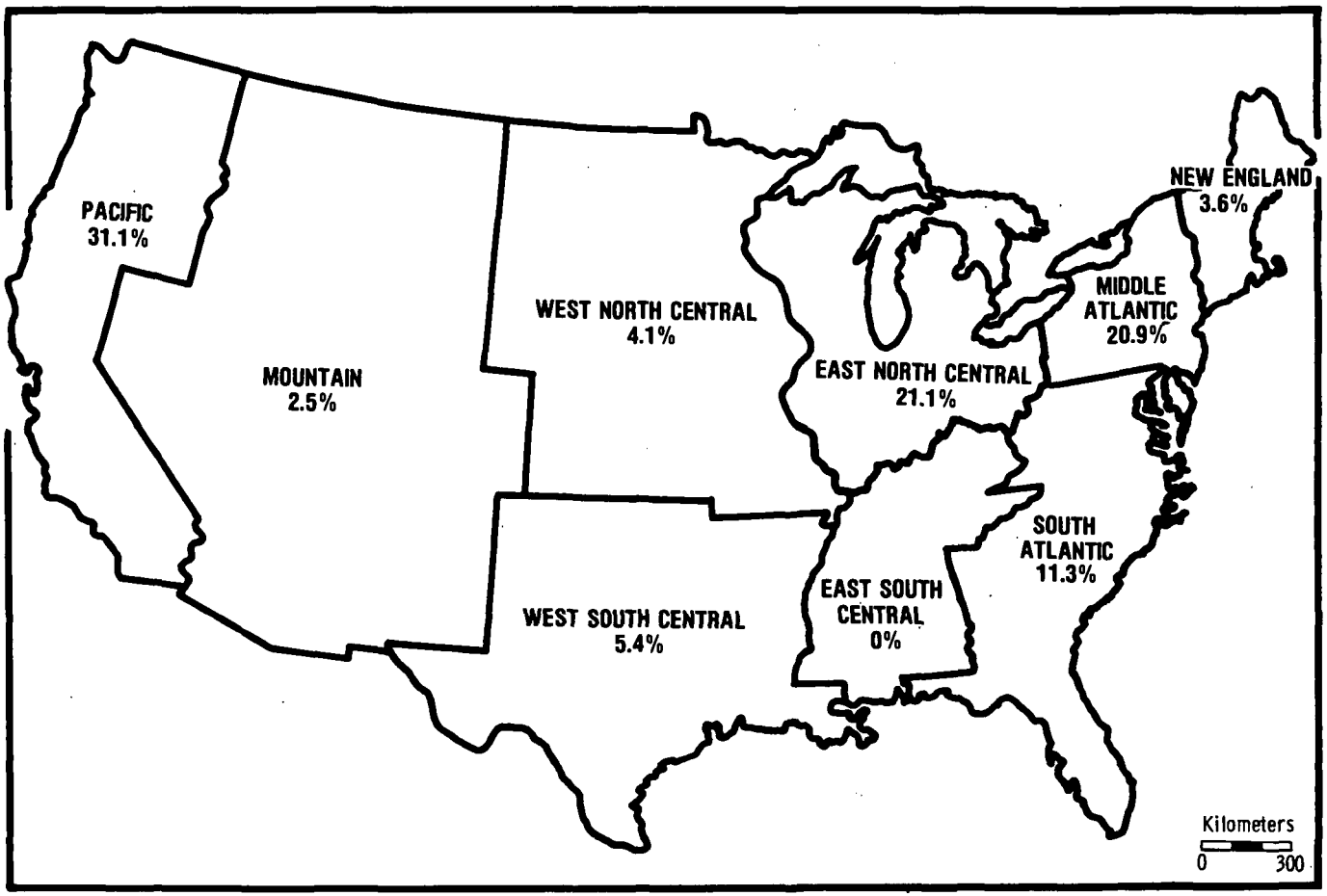


Figure 1.14 PERCENTAGE OF DISTRIBUTION OF AIR FREIGHT ACTIVITY
(Source: Douglass Class Report, 1978, p. 16).

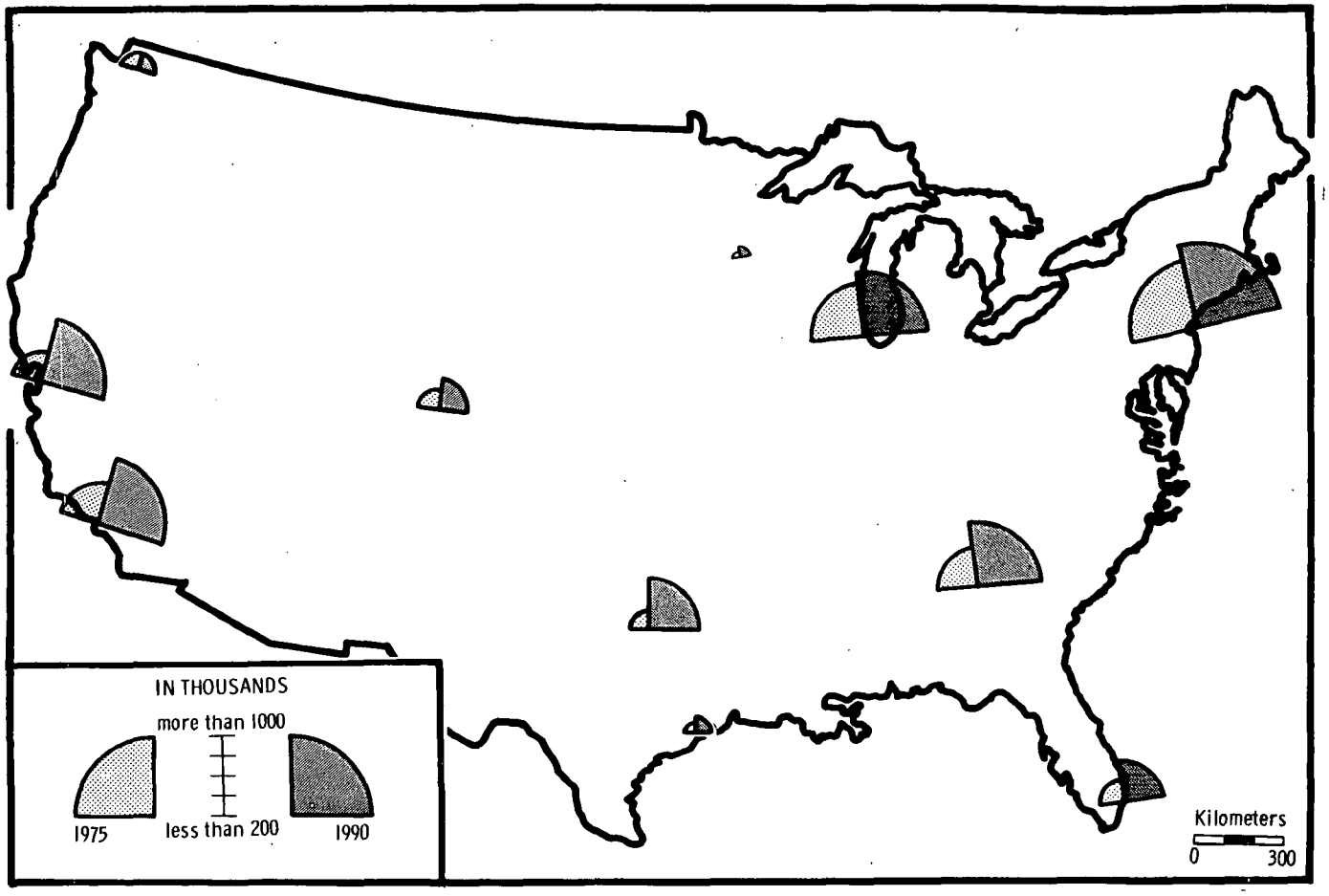


Figure 1.15 1975 & 1990 AIR OPERATIONS AT LARGE HUBS (Ref. 6)

Table 1.4

A SUGGESTED SCHEDULE FOR OVERNIGHT DELIVERY

Event	Pacific Time	Eastern Time
Truck leaves consignor at Olympia	6:00 p.m.	9:00 p.m.
Truck arrives Seattle Airport	7:00 p.m.	10:00 p.m.
Feeder-plane departs for S.F.	8:00 p.m.	11:00 p.m.
Feeder-plane arrives at S.F.	9:30 p.m.	12:30 a.m.
Hub-plane departs for N.Y.C.	10:30 p.m.	1:30 p.m.
Hub-plane arrives at N.Y.C.	2:30 a.m.	5:30 a.m.
Feeder-plane departs for Albany	3:30 a.m.	6:30 a.m.
Feeder-plane arrives at Albany	4:00 a.m.	7:00 a.m.
Truck leaves Albany Airport	5:00 a.m.	8:00 a.m.
Truck arrives at consignee	6:00 a.m.	9:00 a.m.

(from Olympia, Wash. to Albany, N.Y.)

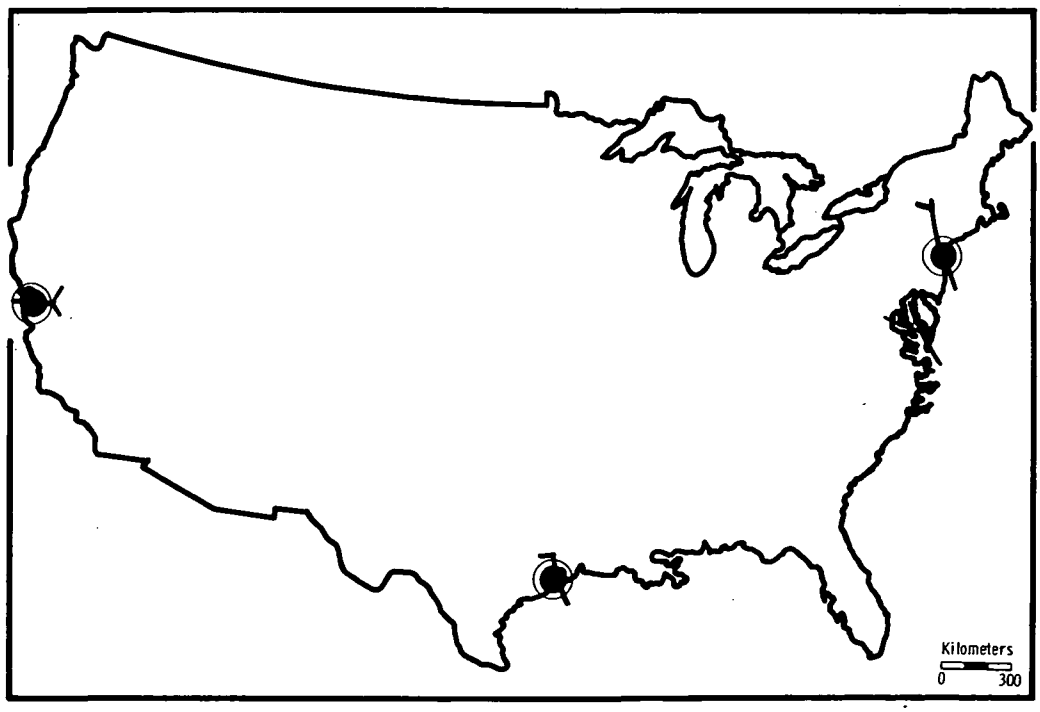


Figure 1.16 DEEP WATERWAYS AT INTERNATIONAL HUBS (Ref. 6)

The average distance flown between these major gateway hubs is of the order of 5000-8000km (3500-5000 miles), suitable for planes like to Boeing 747 or the DC-10. Most of the world's major airlines are now using the B-747 precisely for such missions, and at least 12 carriers employ all-cargo versions of the B-747 (Table 1.4).

To accommodate the water mode for moving containers, there are existing deep waterways near the proposed major hubs (Fig. 1.16). At this stage in the development of standardized containers, the specifications for seaborne containers are not quite compatible with those called for by the air transport industry, especially as far as tare weight and bottom surface is concerned. While some containerships carry their own lighter barges capable of carrying containers along canal access ways, the interchange between air and water may not carry a significant percent of the total cargo even during the cargo period planned for by this system. Nevertheless, there is no harm including the possibility as long as the waterways do exist and the potential is there.

Finally, one other aspect of long range planning incorporated into the design of freightports should be considered. It is conceivable that, by the year 2000:

1) a fully integrated, intermodal air cargo transportation system is in place,

2) all-cargo, long range aircraft are fully operational and fully utilized,

3) the prospects indicate a continued growth of air cargo business, and

4) an even more interdependent world industrial and commercial economy has developed.

At that point, the need for an advanced air cargo craft such as the twin body (C-XX) or the span loader (DLC), which are now on the drawing boards of the major airframe companies, will have been ascertained. In anticipation that new large aircraft will be called for, modern airports now being planned should set aside acreage that could then be developed with appropriate runways and buildings to form the ground support infrastructure for this new generation of aircraft.

1.1.5. Remarks

The hierarchy of hexagonal areas provides for service to all areas, from the smallest and least efficient units to large continents utilizing efficiency of scale. No pure network organization will do justice to all special cases that have developed historically; there simply is not enough flexibility in any single system or concept. Elsewhere in this chapter special cases of networks have been discussed. The above network is intended to serve as a unifying framework.

The impact of the system upon the landscape of the United States will be primarily in the vicinity of the proposed new air cargo terminals, i.e., the San Francisco, the New York, and the Houston regions. The U.S. Secretary of Transportation sees need for at least ten new major airports for the year 2000 (refs. 5,7,8,9). It is here proposed that the three hub freightports be placed in uncongested, rural settings, preferably utilizing wasteland, certainly not prime farmland. It may be necessary to build additional limited access roads which will produce the usual consequences for nearby populations, streams, and wild life (see Section 5.3). The separation of this cargo traffic from passenger traffic at existing mixed-use airports will contribute to an easing of congestion both of air lanes and urban access roads. Subsequent development of industrial parks around new hubs can be monitored carefully and controlled by local authorities as part of the overall planning and design of the new airports.

1.2 CONNECTIVITY AND SCHEDULING

The preceding section of this chapter considered the probable locations of the cargo ports. These locations represent the nodes (terminals) of the network. In this section, the edges (links or routes) connecting the nodes are considered. In addition to the problem of edge determination, the closely allied problem of scheduling is treated in this section. Important considerations relative to scheduling include such disparate concerns as backhaul, shippers needs, air freight carrier (AFC) network, competitive AFC's, airport authorities and terminal availability, curfews, regulations, and the Postal Service. These topics will be discussed at some length.

Out of this deliberation will come important implications for aircraft size. In fact, several air carrier planners (notably Pollack, ref. 10 and 11, and Glenn, ref. 12) allude to the almost parallel planning required to solve the scheduling and fleet planning problems. This is depicted in Figure 1.17. Additional details regarding aircraft mix will be discussed in Section 1.6. The intimate relationships between network connectivity, scheduling, and fleet sizing, however, are discussed in this section.

It is worth noting that even though the network, fleet-sizing, and scheduling problems should be solved simultaneously (or in concert), any formal combinatorial optimization approach is computationally infeasible. For a simple combined problem consisting of a 40-node network and two different aircraft sizes, the combinatorial design space is of dimension nearly 13 000. Considering that a combinatorial design space problem of dimension 40 can take weeks to find the extremum on a high-speed computer, it becomes understandable as to why the combined, total optimization problem cannot be solved. It must be solved as a collection of subproblems, each of whose dimensionalities is considerably reduced by heuristic design rules. It becomes necessary, therefore, to treat these subproblems in concert and separately as well. They are considered jointly here and dealt with as isolated subproblems later.

In addition to scheduling aircraft, the total scheduling problem also involves the use of any surface transport required to move the freight from the shipper's dock to the freightport and from another port to the consignee's dock. Thus the total scheduling problem requires coordination of the operations of the air carriers with that of the surface carriers, all of which must be tailored to the shipper's needs. In this design, the freight forwarder is assumed to handle the surface transport, and the freight forwarder adjusts his schedules to accommodate both shipper and air carrier. Even so, the air carrier's schedule can be fitted appropriately into the transportation windows needed by the freight forwarder to satisfy the customers. It is conceded that a vertically integrated carrier system may be operational by 1990 in which one company handles all surface and air transport, but this certainly is not the usual case today. The total system is depicted in Figure 1.18. It is apparent that surface transport and air transport schedules must be coordinated.

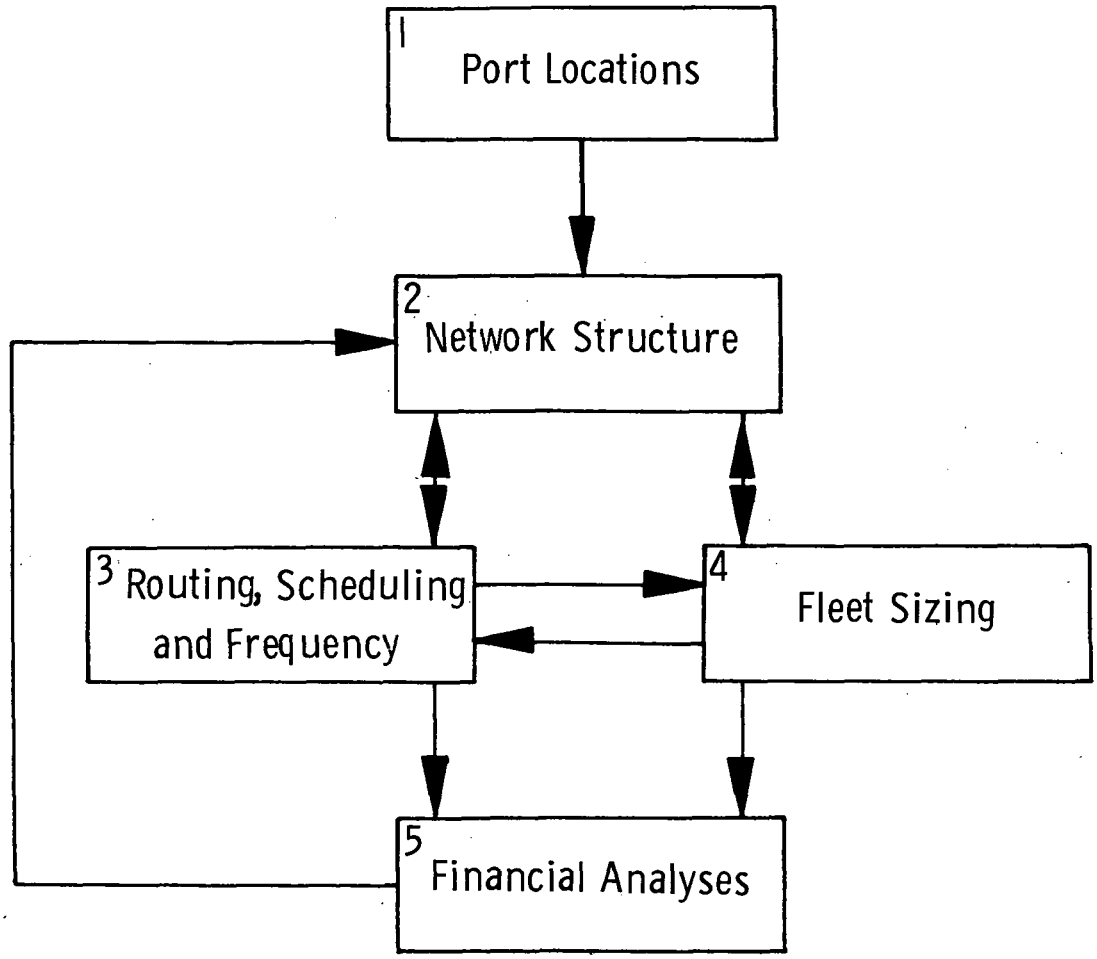


Figure 1.17 BASIC COMPONENTS IN AIR FREIGHT CARRIER PLANNING AND THEIR INTERACTIONS

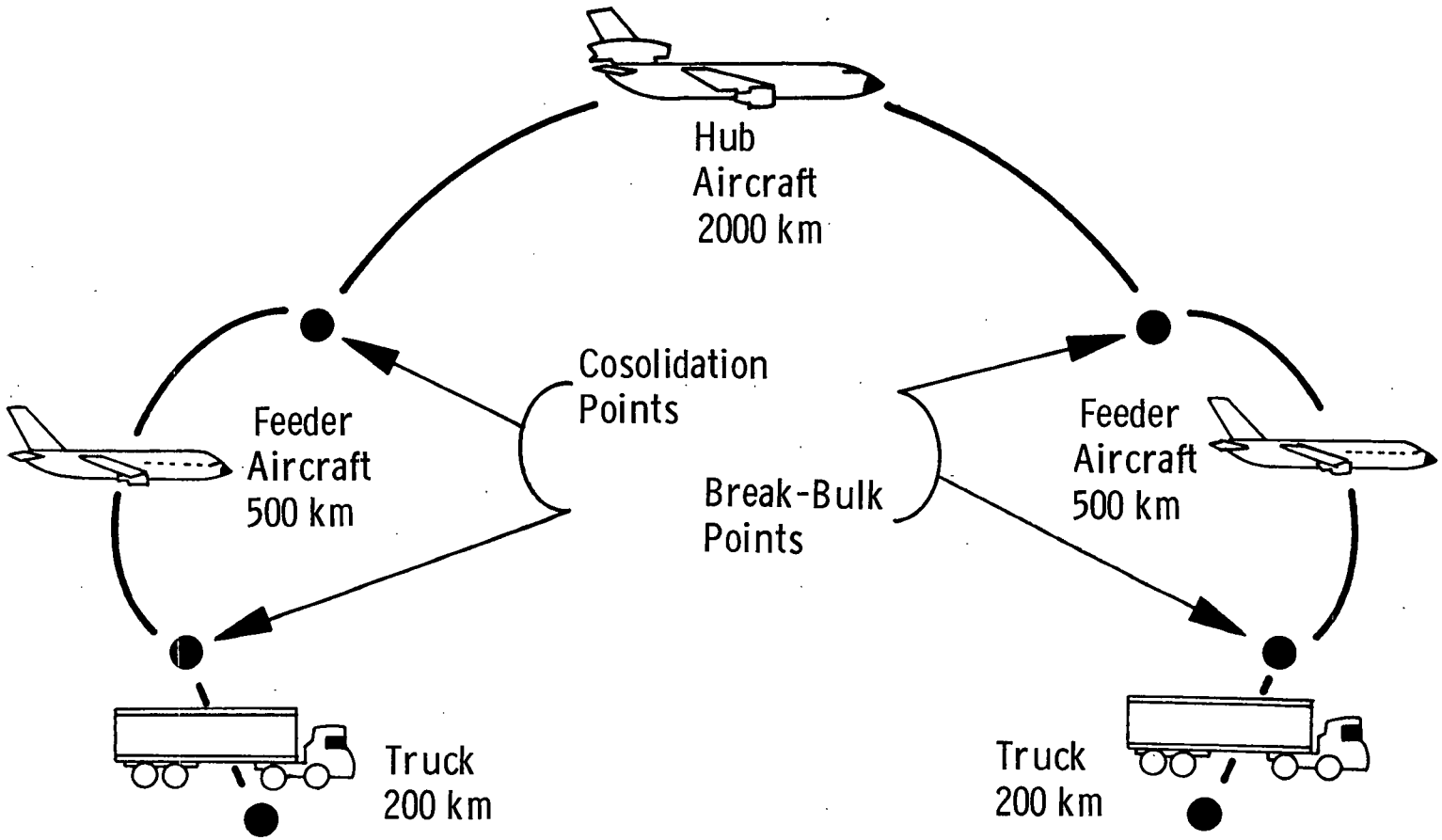


Figure 1.18 A PICTORAL REPRESENTATION OF AN AIR CARGO SYSTEM SHARING INTERFACES WITH TRUCK, RAIL, AND SHIP TRANSPORT SYSTEMS

In what follows, a discussion of the needs of the shipper is followed by a discussion of connectivity design in terms of direct versus hub-spoke approaches. Formal network designs are proposed which are compatible with the needs of the shipper, the air carrier, and other interested parties.

1.2.1. Characteristics of the Shipper (Consignor)

At the outset of the scheduling and connectivity design process, it seems appropriate to consider the needs of the shippers in order that the cargo system will accommodate their transportation requirements. As pointed out by Pollack (ref. 10), cargo tends to arrive at the airline during a short concentrated period in the latter part of each workday. The airline, in turn, has strong pressures to fly at night so that the cargo is ready to be delivered to the customer in the morning of the next workday. Both the departure and the arrival distributions are thus sharply unimodal. The allowed cargo shipping time is approximately one half day, and then it usually increases in increments of 24 hours.

Glenn (ref. 12) also characterizes the shipper in an analogous way.

> "He wants as many flights as possible in the late evening, so that he can clear the products manufactured that day. As a rule, he is not interested in flights on weekends, when his plant is not producing. He wants through flights, as he recognizes that, on occasion, the paperwork which accompanies his shipment sometimes goes astray when the shipment must be transferred from one flight to another."

These sentiments are corroborated by similar statements found in Taneja (ref. 13) who also maintains that shippers prefer late afternoon and evening flights which are nonstop or direct. Taneja maintains that the Postal Service is interested in flight departures ranging from 6 P.M. to 1 A.M. and in arrivals from 4 A.M. to 6 A.M.

In addition to in-transit time, the shipper is also concerned about cost of transshipment and possible losses due to breakage, theft, and pilferage. With the exception of cost, all of these factors comprise the quality of service which the shipper receives from the total air cargo system including the air carrier, the freight forwarder, any terminal processors, etc.

1.2.2. Connectivity Trade-offs: Direct vs Hub-Spoke

Previously, a network was described as consisting of nodes and edges, as shown in Figure 1.19 below. It is customary to speak of connectivity as the degree to which the nodes of the network are connected by edges. The minimum number of edges in the network is the number of edges required to connect all the nodes. A minimum edge network is one with very low connectivity, whereas a network with a great many redundant edges, such as one in which an edge proceeds from every node to every other node, possesses a very high degree of connectivity. From Figure 1.19, the similarity between a network with low connectivity and the hub-spoke construct is apparent, whereas a network with

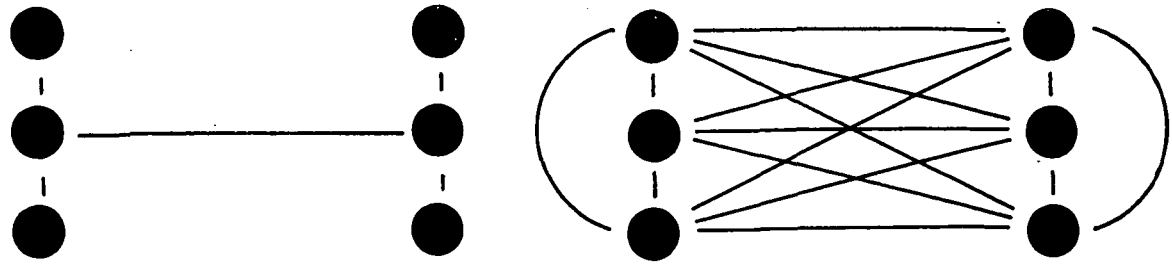


Figure 1.19 SIMPLE SIX-MODE NETWORKS ILLUSTRATING THE TWO EXTREMES OF CONNECTIVITY

high connectivity approximates our understanding of direct routing. Note that in the hub-spoke network, there are five edges, whereas in the direct network there are fifteen.

Clearly, the hub-spoke arrangement lessens the number of routes. For a fixed number of aircraft, this allows a greater frequency of flights; conversely, for a fixed frequency of flights, the number of aircraft required to service the network increases as the connectivity of the network increases. If the number of aircraft and frequency of flights are fixed, then load factors will be higher in the hub-and-spoke arrangement.

Gordon and de Neufville (ref. 14) developed a network model based upon the concept of schedule delay, D, which is a measure of frequency of service. The objective is to minimize D on all i routes in a network through appropriate assignment of the number of aircraft, N_i, to each route. Thus, N_i is their only decision variable.

This is a legitimate problem when the regulatory environment is as rigid as it was during the late 60's and early 70's. At that time, the airline routes were pretty well fixed. The type of aircraft were fixed. About the only variable that an airline had at its disposal to manipulate to give it a service advantage over its competition was frequency of service, determined, of course, by the number of aircraft assigned to a route. Stated mathematically, their problem was

$$\left.\begin{aligned} &\min D = a \textstyle\sum_i v_i \, (1-p_i{}^s)^{-1/s} \, N_i{}^{-1}, \\ &\text{subject to} \\ &\textstyle\sum N_i ct_i \leq S, \end{aligned}\right\} \qquad (1.1)$$

where a = proportionality constant,

v_i = volume of passengers along a link or route i

p_i = load factor along link i, $0 \leq p_i < 1$

c = aircraft capacity in terms of seats,

t_i = distance of link i,

S = total capability of the aircraft fleet in terms of seat-miles in a given day, and

s = undetermined constant, usually picked to be 1.

The model assumes (1) the line-haul time is relatively fixed, (2) the delay in the movement of any item through the transportation network is an important element in its level of service, (3) delays occur at the nodes of the network and are independent, (4) demand is stochastic and therefore load factors are stochastic as well, and (5) the level of investment capital is fixed, fixing the number of aircraft.

Implications for network shape and aircraft size which are derived from solving this optimization problem are of interest. The analysis suggests that the network which minimizes schedule delay is often, but not always, the one with the smallest number of links connecting all points. Further, it shows that, as a given network becomes more saturated (i.e., as load factors are increased), the network should become more highly connected in order to minimize delay D. The analysis also shows that when there are many parallel links that are possible between two groups of cities, schedule delay is minimized when the number of such links is reduced to one, and one city in each group acts as a hub. Also, it must be recognized that low connectivity networks will necessarily require more tonne-kilometers -- some of the traffic that could be routed directly on more connected networks has to be detoured on the other. Thus for low connectivity networks, both load factors and tonne-kilometers are higher than for high connectivity networks serving the same geographic area.

In terms of aircraft, the model shows that the immediate effect of introducing larger aircraft on the network is, in general, to increase delays, assuming the capital investment in aircraft remains fixed. A concurrent effect of larger aircraft is to increase the desirability of less-connected networks for any given level of traffic.

Two types of networks were compared using the Gordon and de Neufville model -- the so-called hub-spoke networks (that form minimal edge networks) and networks with more direct service. As expected, the results show that

hub-spoke networks are preferable for minimizing total schedule delay D. This is because there are fewer routes to service and therefore more aircraft are available per route. The increased number of aircraft available per link diminishes total schedule delay D because $D \simeq f(1/N_i)$ -- that is, D is inversely proportional to the number of aircraft per link N_i.

Another consideration is that of cargo connections at the nodes of the network. The more numerous the aircraft and flights, the more opportunities there are to schedule connecting flights.

Finally, to minimize schedule delay D, the model shows that the number of aircraft allocated to a link is a direct function of the volume of traffic, vehicle size (number of seats or cargo capacity), and length of trip, roughly according to

$$N_i = \frac{v_i}{c} + K\sqrt{\frac{v_i}{t_i}}, \text{ where } K = \frac{S - \sum_i v_i t_i}{c \sum_i \sqrt{v_i t_i}}, \qquad (1.2)$$

which requires that load factors p_i be greater for longer trips and in denser markets. The expression above is the closed-form solution to the problem expressed by Equation (1.1) for s = 1.

In this context, the concept of optimal connectivity takes on meaning in the sense that the total network schedule delay may not be the overall optimum if there is a high volume route that would consequently have to connect with other flights through a hub. In this case, that cargo might most appropriately be linked directly (in terms of origin-destination pairs). Thus low connectivity networks require more transfers and handling of cargo, whereas high connectivity networks greatly diminish the number of available flights. An optimal tradeoff between these two extremes is required.

1.2.3. Toward a Network and Network Design Procedure

Formal networks are proposed for both the domestic and the international settings which incorporate these concerns. These are presented in Figures 1.20, 1.21, 1.22, and 1.23 on the following pages. Figure 1.20 exhibits the domestic trunking network illustrating the necessary total connectivity among domestic hubs. Figure 1.21 illustrates the domestic regional networks which connect the various spoke terminals with each hub. Figures 1.20 and 1.21 represent the minimal edge network required to connect all nodes shown on the network. To accommodate heavy traffic routes, the direct network shown in Figure 1.22 is superimposed upon the minimum edge network shown in Figures 1.20 and 1.21. The direct network allows for better service between paired cities experiencing heavy traffic volume. It is estimated that roughly 50% of the domestic freight will fly nonstop with this network, 25% of the freight will require one transfer, and 25% of the freight (by weight) will require two transfers. No freight will ever require more than two transfers while it is in the possession of the air carrier; however, two additional transfers will generally be required to deliver it door-to-door.

Figure 1.23 exhibits what is considered in ref. 15 to be the necessary route structure between international hubs. In addition to the three domestic hubs previously chosen, the international network requires hubs cited in Columbia, Japan, Malaysia, Europe, South Africa, Middle East, and the Soviet Union.

At least as important as the networks proposed here is the methodology by which they were arrived at. The steps of our method are discussed below:

1) Use central place theory to locate the nodes of the network -- i.e., the hubs and spokes.

2) Connect the hubs with a network of edges of maximal connectivity.

3) Connect the spoke nodes to their respective hubs, where each spoke node is associated with the hub closest to it.

4) Study the demand volume between city-pairs and connect by means of direct links those city-pairs with the heaviest demand volume. (Those city-pairs whose aggregate demand volume represented 50% were connected in this design).

The approach is evidently quite heuristic and should be contrasted with more formal optimizing approaches that could be used. Even for an optimization problem involving network design (edge determination) alone, the dimensionality of the combinatorial problem is still quite high. The literature suggests that heuristic design schemes hold more promise than do optimizing ones. In any case computer-assisted approaches, if used at all, have their outputs modified strongly before being placed into service (refs. 10, 11, 12).

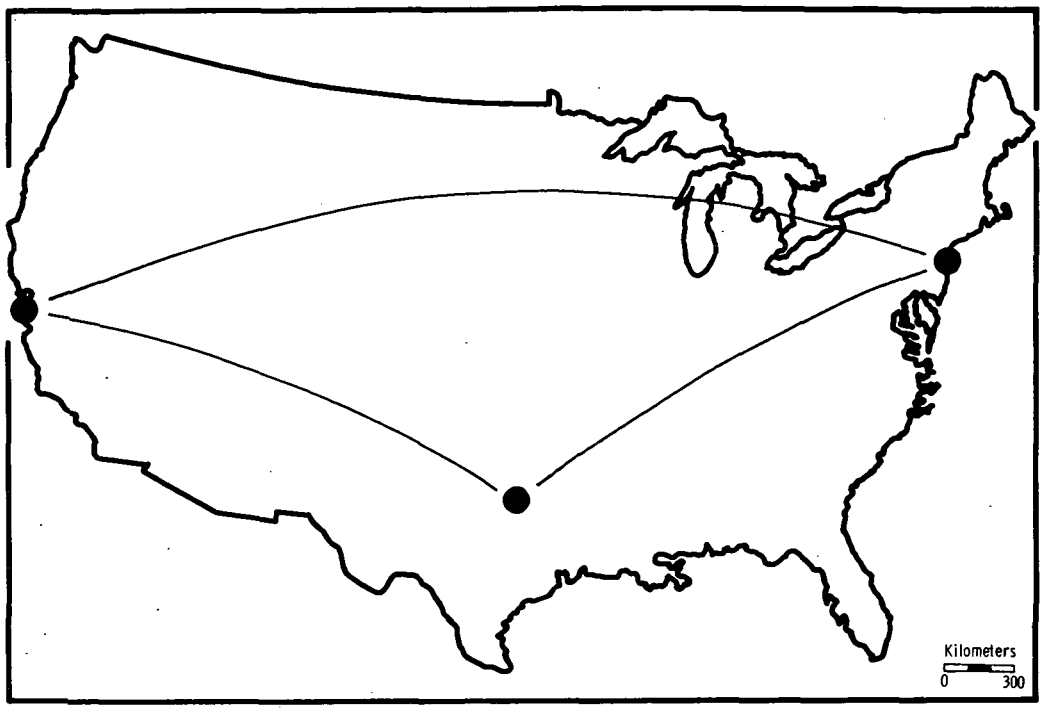


Figure 1.20 DOMESTIC TRUNKING NETWORK BETWEEN HUBS

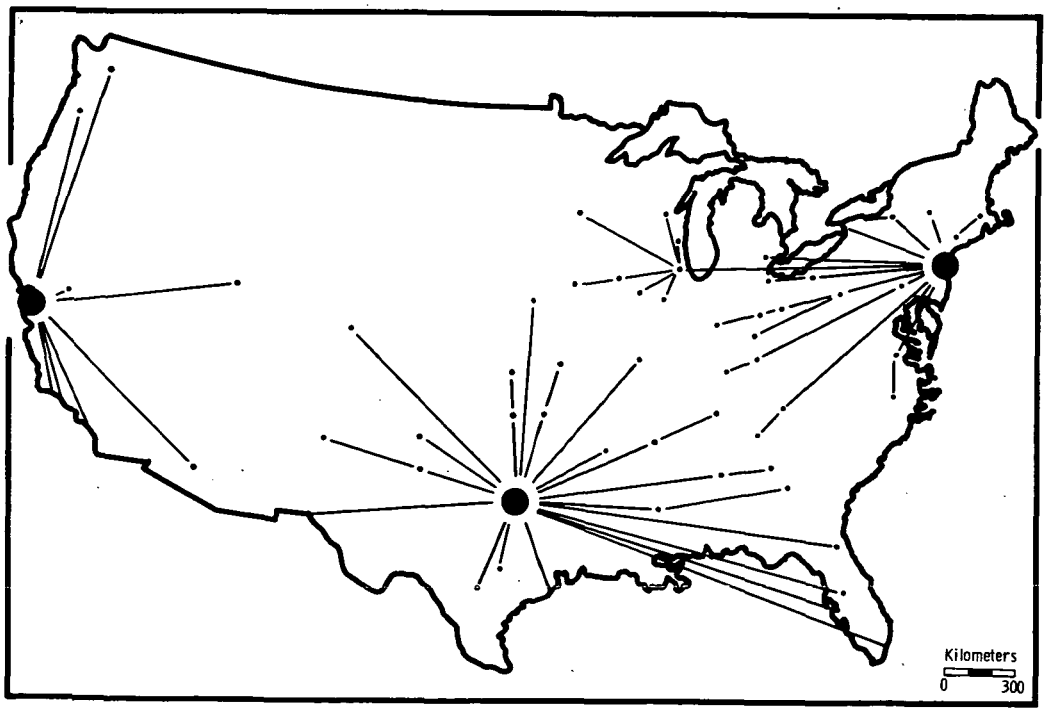


Figure 1.21 DOMESTIC REGIONAL NETWORK CONNECTING SPOKE TERMINALS WITH EACH HUB

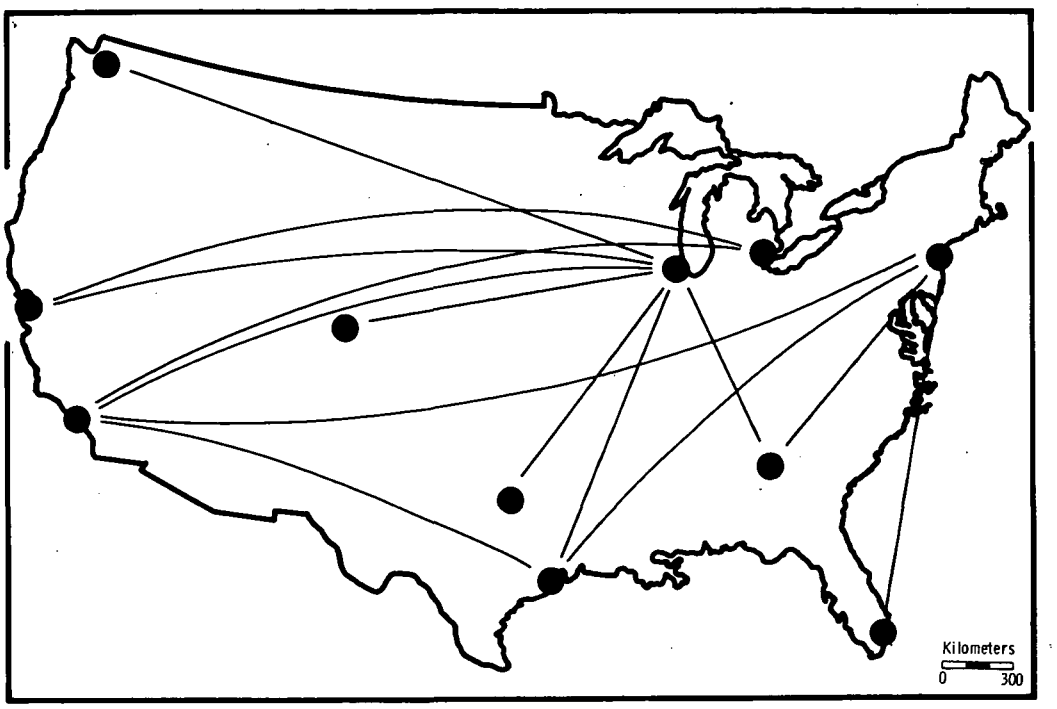


Figure 1.22 DOMESTIC DIRECT NETWORK CONNECTING CITY-PAIRS WITH HEAVY TRAFFIC

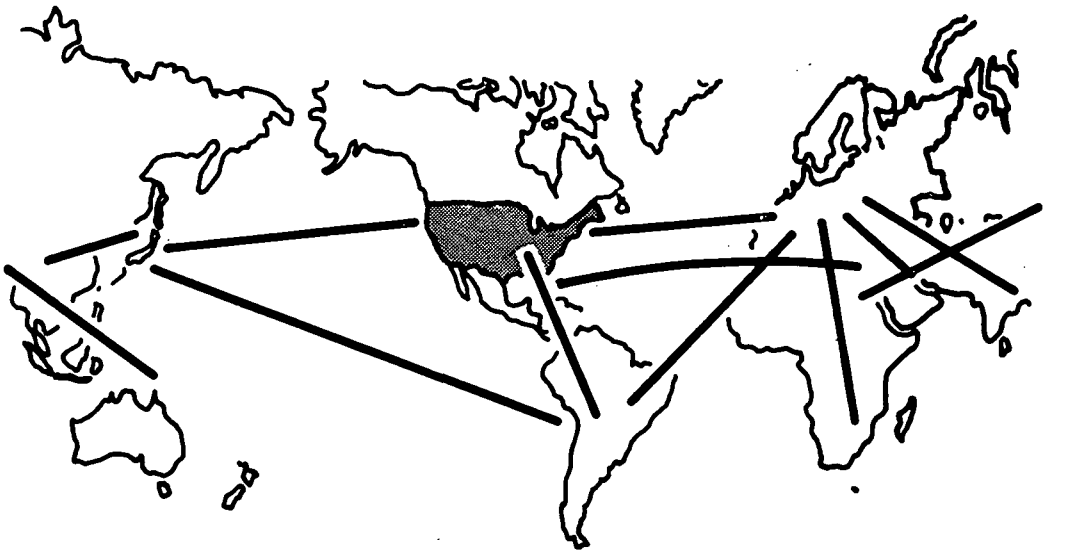


Figure 1.23 INTERNATIONAL NETWORK SHOWING ROUTES BETWEEN HUBS

1.2.4. Scheduling Considerations

Scheduling refers to the manner in which an existing or proposed aircraft fleet is assigned to a predetermined network. There are, according to Pollack (ref. 11), two ways in which heuristic scheduling can be accomplished; however, only one of these is at all practical. The practical scheme described by Pollack is discussed later in this section, as is one optimizing scheme. The scheduling problem has two principal components -- route or cycle determination and frequency of service. The scheduler must decide what aircraft will fly which routes and how frequently each route will be flown.

The two heuristic approaches which could be employed are described briefly here. In the first method, one assumes the fleet sizes are given and the problem is to determine the best possible flight departure times. This method is very complex and is not treated in any of the published literature. In the second method, one begins by specifying a departure range for each flight. The problem is to determine the actual departures such that fleet sizes are minimum. This is the method that will be discussed later.

According to Glenn (ref. 12) an air carrier schedule is a compromise which must consider the interests of many parties as shown in Figure 1.23 (the abbreviation AFC refers to Air Freight Carrier).

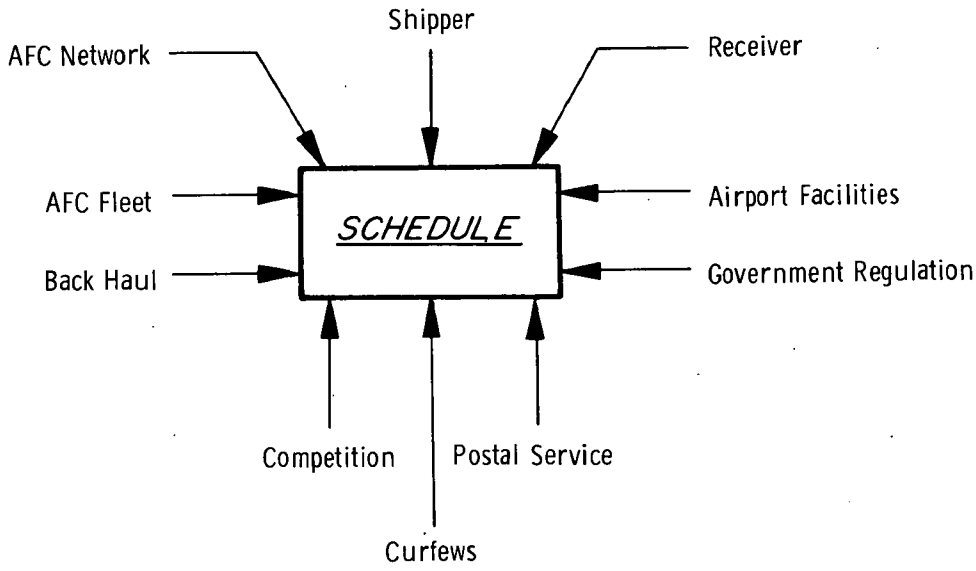


Figure 1.24 FACTORS WHICH AFFECT AN AIR FRIEGHT CARRIER'S SCHEDULE

In addition to the factors listed above, still other factors enter into the scheduling problem, including:

1. aircraft operational conditions and restraints (no two aircraft types are alike),
2. integer variables,
3. seasonal demand,
4. station restraints,
5. marketing continuity
6. nonlinear revenues,
7. nonlinear costs,
8. fixed and variable costs,
9. major (non-aircraft) cost expenditures, and
10. route authorities

Some of these factors are treated in ref. 10. The implication of these myriad considerations is that computer-assisted scheduling has enjoyed only limited success in the airline industry as pointed out by Glenn (ref. 12).

From this extensive list of factors, this discussion will treat only three important topics -- the AFC network, the problem of backhaul, and fleet size. The shipper's concerns relative to scheduling were dealt with previously. Discussions of the remaining considerations are found in refs. 10, 11, and 12.

It is important to include as well the scheduling concerns of those freight carriers in the air cargo system that are not dedicated air freight carriers --namely, the trucking forwarders, and the use of belly space to transport freight on the air passenger carriers. It is assumed here that scheduling of air passenger carriers will be accomplished without significant consideration being given to cargo. And trucking schedules will be determined after dedicated air cargo schedules are established.

The effect which the AFC network has upon scheduling was also considered in the previous section. That discussion is summarized by stating simply that as the connectivity of the network goes up, the frequency of flights must go down and conversely for a fixed capital investment in aircraft. In addition, an increase in connectivity causes decreases in tonne-kilometers and load factors for a fixed captial investment in aircraft.

1.2.4.1. Backhaul

Backhaul refers to loading imbalances that are either characteristic or periodic on certain routes. An aircraft may be almost fully loaded along certain directional links and nearly empty along others. The problem is partially solvable through judicious selection of (1) aircraft size, (2) routing design, (3) frequency of service, (4) real-time rescheduling or reassignment. The backhaul problem is treated in ref. 15 from a scheduling viewpoint. References 15 and 16 provide excellent analyses of the hub and wheel scheduling problem taken in the context of trucking.

However, the backhaul problem also has implications for marketing as well. At each node where serious imbalances exist, the air freight carrier must attempt, through legitimate marketing strategies, to solicit air-eligible cargo that is currently being transported by surface transport systems. Briefly summarized, air-eligible cargo is containerized cargo (as opposed to bulk cargo). More on the subject of marketing is discussed elsewhere in this report.

1.2.4.2. Fleet Planning

Glenn (ref. 12) illustrates the enhanced profitability that can come from the use of smaller aircraft flying more frequently and making fewer stops on routes where demand is not high. In fact, Glenn cautions against the use of aircraft that are too large. Large aircraft may be less profitable for the following reasons:

1. "additional expenses are incurred with the large airplane when it is stopped unnecessarily, and

2. the fleet size relative to the airplane size is more attractive with the smaller airplane, because of increased frequency and opportunties for direct routing."

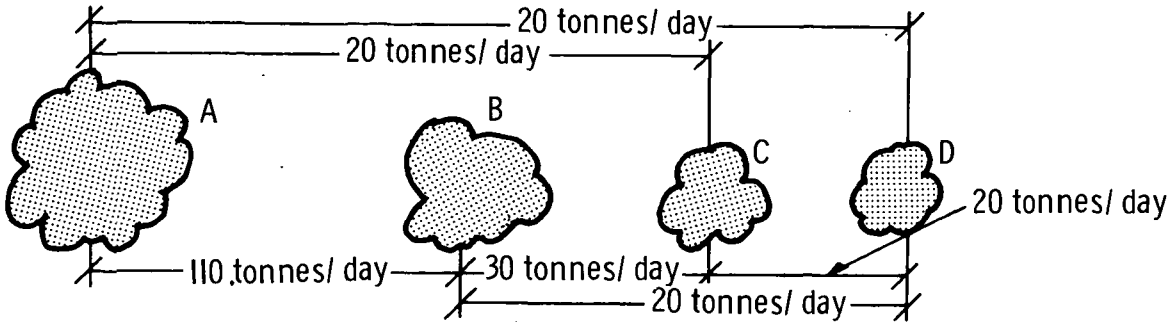
These points are illustrated by the example shown in Figure 1.25 (adapted from ref. 12). In this example, there are four population centers located roughly 320 kilometers apart and roughly in line.

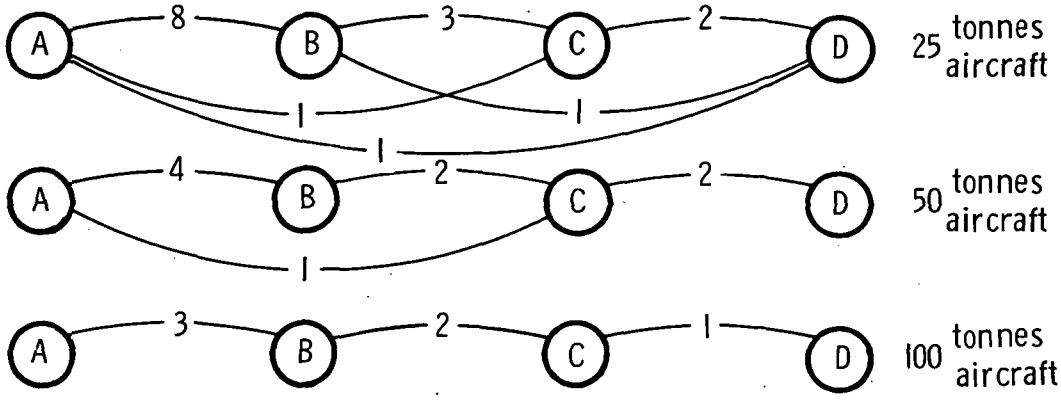
For the network shown in Fig. 1.25, small aircraft provide many direct flights, whereas large aircraft require many intervening stops. As shown, the smallest aircraft is the most profitable for this network. In Glenn's experience, the long-haul flights are most profitable than the short-haul flights, so that it is desirable to not destroy the profitability of the long-haul by carrying it on a series of short-haul route segments. Finally, the increased amount of direct routing possible with the smaller aircraft provides better service to the shipper because of the diminished probabilities of loss, pilferage, or damage due to handling and because of possible diminished schedule delay as discussed previously.

1.2.5. Scheduling Design Procedures

In this section, several schemes for schedule determination are discussed. The first of these schemes is taken from ref. 11 and is heuristic. In this method, one specifies a departure range for each flight and then determines the actual departures such that the fleet size is a minimum.

It is also assumed that the complete set of all flights is given, including the aircraft type, the itinerary, the block, and through times. (Block time is the sum of flight-time and taxi-time between cities. Through time is the time the aircraft is parked at the terminals.) Assuming each aircraft is capable of 9.5 block hours per day, it is possible to estimate the fleet size required by the frequency plan. Since departure ranges are specified in terms





Airplane Size	25	50	100
Fleet Size	3	2	1
Daily Utilization (HRS)	9.1	7.2	9.0
Av. Stage Length	250	222	200
Revenue - $	3.0M	3.0M	3.0M
Cost - $	2.7M	3.8M	4.8M
Op. Profit (Loss) - $	0.3M	(0.8M)	(1.8M)

Figure 1.25 ECONOMICS OF AIRCRAFT SIZE FOR A TYPICAL NETWORK

of a triplet consisting of minimum, preferred, and maximum for departure times, the problem is to select a good triplet for each flight and to determine the minimum active fleet size required to undertake the flights.

The actual schedule construction process is iterative in nature, where each iteration consists of four steps. (1) A triplet of departure times is assigned to each flight. (2) The flights that are compatible in the sense of requiring comparably sized aircraft are linked to form a minimal number of strings (each string corresponds to the set of flights assigned to one aircraft for one schedule period). (3) The cycle diagram is constructed for each aircraft type (the cycle diagram represents the sequence of strings that one aircraft undertakes on successive days or weeks). (4) The total result is evaluated, changes are made to certain parameters, and the process is repeated.

The procedure is predicated upon the following propositions. Initially, each string of flights consists of a single flight with one aircraft assigned to it. Since an aircraft is required for each string, the objective is to form the smallest number of strings. This is done by linking flights together at each city. In this method, the number of unlinked arriving flights is always equal to the number of unlinked departing flights at each city. By linking arriving flights to departing flights, an optimal fleet solution results.

The procedure consists of three phases. Using the preferred departure times, each unlinked arriving flight is linked to the closest unlinked departing flight at each city in the first phase. In the second phase, the actual departures are allowed to shift for those flights that are unlinked at a city. An unlinked pair is picked and the arriving flight is shifted backward as far as possible, while the departing flight is shifted forward as far as possible. If the respective times are in proper relationship to each other, the pair is linked. For flights which have previously been linked, the entire string must sometimes be shifted. The second phase terminates when all unlinked pairs have been chosen and no further linkages are possible.

In the third phase, a city is selected and every linkage is broken at this city. The linking procedure in phase two is then reapplied. This may result in more or fewer linkages being formed at the city in question. If fewer, then the original linkages are restored.

This heuristic procedure works better when the shift ranges are small. Since some loss in utility or performance results from not departing at the preferred departure times, it is desirable to keep each actual departure time as close as possible to the preferred time. A good criterion is a minimum for the sum of squares of the deviations, where a deviation is the difference between the actual and preferred departure time.

Next the flight scheduling problem is formulated as an optimization problem. Let there be M different types of flights to be performed and A aircraft available. Flight type j (j = 1, ... , M) takes time w_j and must be performed r_j times. The intent is to allocate flights to aircraft in such

a way that W (time of completion of the total job) is minimized for a given A. This problem is the inverse of the trim problem. The trim problem is well-known in the operations research literature.

$$\begin{aligned} &\text{minimize } W \\ &\quad x \in X \\ &\text{subject to } \sum_{j=1}^{M} x_{ij}\, w_j \leq W \text{ for } i=1, \ldots, A \\ &\qquad \sum_{i=1}^{A} x_{ij} \geq r_j \text{ for all } j=1, \ldots, M \\ &\qquad x_{ij} \geq 0, \text{ integer, for } i=1, 2, \ldots, A \text{ and } j=1, 2, \ldots, M \end{aligned} \tag{1.3}$$

Here x_{ij} refers to the number of flights of type i flown by aircraft j and X is the matrix of all x_{ij}'s. The quantity w_j represents the block time required of flight j and the first constraint above insures that no aircraft gets scheduled for more than W time periods. The second constraint above insures that each flight or link gets flown r_j times.

The trim problem is an integer programming problem whose solution would be difficult to obtain in any reasonable amount of computer time for M larger than 40. Also, there may be additional constraints in terms of aircraft assignments to flights. The problem is solvable using cutting plane and branch-and-bound methods discussed in refs. 17 and 18. Of particular applicability is the method due to Balas (ref. 19). In some respects, this model resembles that found in ref. 20. Analogous or related models are described in refs. 21-26.

The inverse trim problem posed above is much easier to solve, as its solution can be approached heuristically. Preston (ref. 20) shows that an optimal solution to the more interesting trim problem can be obtained from the optimal solutions of a sequence of inverse trim problems.

1.2.6. Toward a Feasible Domestic Schedule

For the shipper's interests to be accommodated, what is suggested below is a schedule intended to deliver any airfreight item, which enters the air freight system by 6:00 p.m. local time, before noon the next day if its destination is within the continental United States. For shippers who do not require overnight delivery, a 36-hour service could be provided at a lower cost. We consider first the feasibility of overnight service -- the sort of service which is now being provided by Federal Express.

In most cases, perhaps as many as 90%, it would be possible to deliver before 9:00 a.m. the next day. Consider, for example, an item that must be transported from a site near Olympia, Washington, to a site roughly an hour's drive from Albany, New York. The freight moves first by truck to a spoke airport at Seattle. From there it is transported to San Francisco by feeder aircraft. From San Francisco it proceeds via hub aircraft to New York; from New York it is transported by feeder aircraft to Albany. At Albany it is placed on a truck and taken to its consignee at Schenectady. This is a worst case because the freight is moving from west to east, losing 3 hours (the difference in local times) in the process.

Apparently, this move requires two truck hauls each of one hour duration, two feeder-plane hauls of roughly 1.5 and 0.5 hours duration, and a hub-aircraft long haul of roughly four hours duration. In addition, there are two truck-to-plane transfers and two plane-to-plane transfers, each of which is assumed to take one hour. (Lufthansa unloads and loads its 747's in 45 minutes, ref. 28). The total time required to accomplish this delivery is roughly 12 hours. Add to this the three hours of lost time accruing from west-to-east travel, and it becomes clear that a package placed on a truck in Olympia at 6:00 p.m. can be delivered in Schenectady by 9:00 a.m. the next day.

An appropriate schedule for this case must insure that enough time between the arrival of one leg of the trip and the departure of another leg is allowed to accomplish the transfers. Such a schedule is shown in Table 1.4. In light of this worst-case situation, general guidelines, such as the following, relative to domestic overnight cargo movement can be drawn.

1. Feeder aircraft should arrive at the hub airport not later than 9:30 p.m. for west-coast to east-coast movements. Feeder aircraft should arrive no later than 11:30 p.m. at the southern hub, and no later than 12:30 a.m. at the eastern hub.

2. Hub aircraft must depart no later than 10:30 p.m. for west-coast to east-coast movements. Hub aircraft must depart no later than 12:30 a.m. from the southern hub, and no later than 1:30 a.m. from the eastern hub.

1.2.7. Feeder Aircraft Routing and Scheduling Considerations

The routes flown by the feeder aircraft should be judiciously chosen so as to minimize the fleet size required while maintaining adequate service. It seems appropriate to attempt routing of one aircraft through two hubs. In terms of hub-spoke hexagons, this may be accomplished in several ways as shown in Figure 1.26.

Both routes possess twelve flight legs or four flight legs per aircraft. In some respects, the route network B is preferable because each spoke stop has an intervening hub stop. This would permit complete unloading and reloading at each stop, allowing for the use of smaller aircraft than in network A. However, additional scheduling problems result as it becomes impossible to deliver freight at the spokes in the early morning hours and to pick-up freight in the late afternoon hours, consistent with the needs of the shipper.

In order to achieve efficient utilization of the air cargo facilities (terminals, aircraft, access lanes, etc.), it will be necessary for the air freight carrier to provide incentives (such as lower fares) to encourage the shipper to move his freight at times other than the peak demand period (the early evening hours). If the total demand were distributed more evenly throughout each day, better utilization of the facilities would result and less total capital investment would be required to accommodate those peak periods of demand.

If air cargo demand is seasonal, then dynamic demand scheduling would serve to mitigate this problem by permiting portions of the existing schedule of routes and flights to be changed to accommodate fluctuations in demand. Demand scheduling allows the shipper the opportunity to make a deposit, designate the amount of his shipment and the day the shipment is to be transported about three months in advance. On the day in question, the freight forwarder picks up the shipment, receives the remainder of the transport price, and containerizes the cargo (if it hasn't already been containerized) before delivering it to the air cargo carrier. In this way both the freight forwarder and the cargo carrier can schedule their resources in accordance with demand. If the shipment is not ready on the designated day, the shipper forfeits his deposit and must transmit his shipment at times which suit the convenience of the cargo carrier and freight forwarder. Such an approach would result in generally higher load factors compared to traditional approaches.

A computerized reservation system much like that used for airline passenger travel would have many advantages in this context. First, it would insure that space would be available on the required connecting flights. Second, it would enable the shipper to know each departure and arrival time. Third, it would enable the air freight carrier to utilize dynamic demand scheduling.

The computerized reservation system should have an "intermodal capability". Given the desired departure and arrival times, the system should determine several different transportation plans, each with different levels of service at different fares. Each plan would consist of: (1) the route (and its total cost and time), (2) the links of the route, and (3) the transportation mode

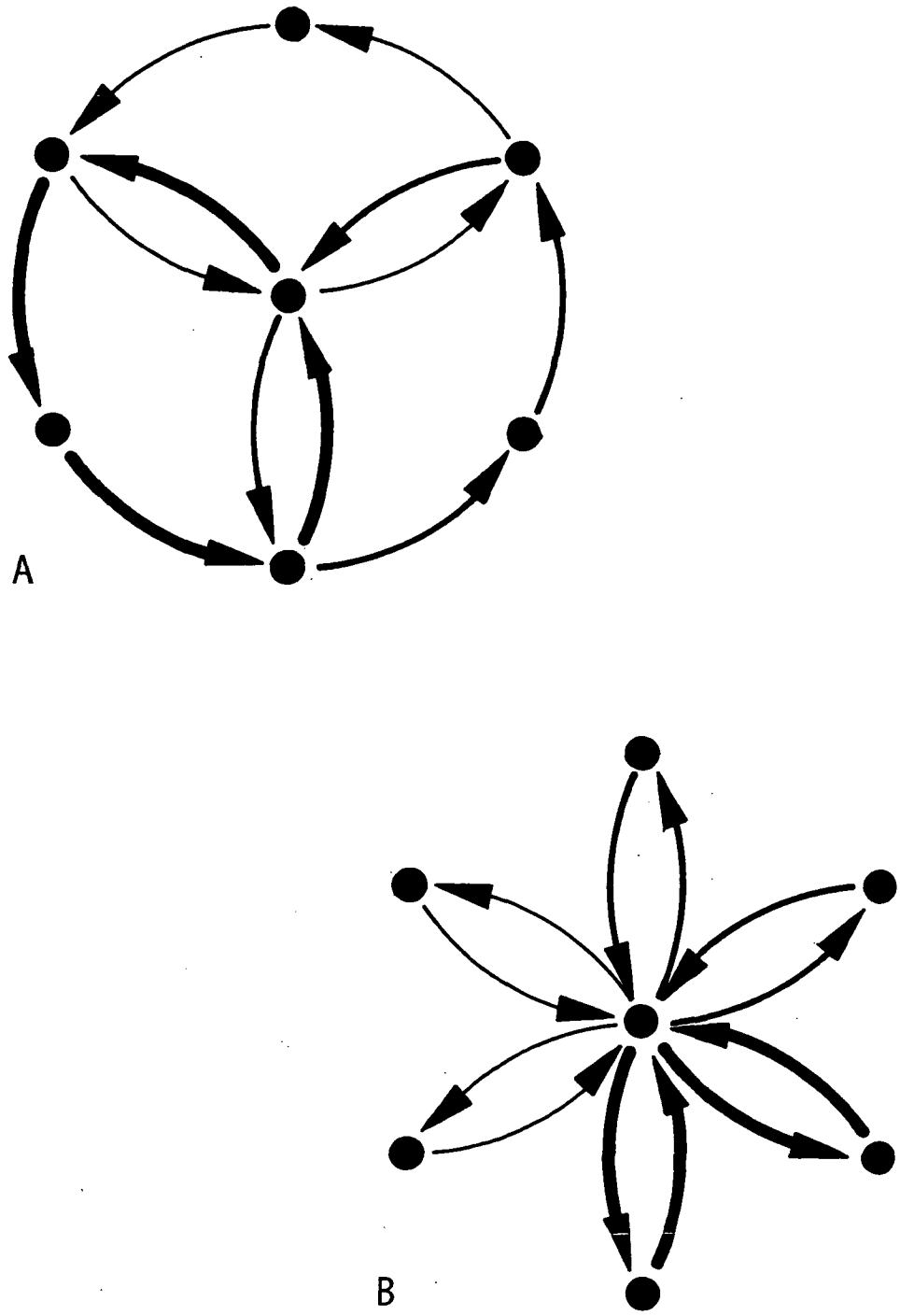


Figure 1.26 TWO METHODS FOR ROUTING THREE AIRCRAFT OVER A HEXAGON HUB-SPOKE NETWORK

used during each link and the time and cost associated with that link. In this way it would be possible to schedule the entire route required to move the freight from dock to dock. All required links in the move could be reserved, and the reservation system would be free to pick only those modes on which vacancies existed.

1.2.8. Frequency of Service

Since at least some of the cargo must be moved during the day, and in view of the domestic schedule developed in Section 1.2.6., it appears that departure times can be scheduled around the highest departure frequencies of the passenger carriers at the airports where both passenger and dedicated freight flights are arriving and departing. This is depicted in Figure 1.27.

Current and projected air cargo demand indicates that as many as six separate daily flights of hub aircraft may be required to handle the heaviest direct routes between city pairs.* Specifically, for one of the heaviest routes -- Los Angeles (LAX) to New York City -- roughly six flights per day on the average will be required to accommodate the projected cargo volume in 1990. This number split among several (say 3 to 5) competitive air freight carriers becomes quite reasonable. It is anticipated that there would be roughly two departing flights of hub aircraft in the morning and four departing flights of hub aircraft in the evening around 10:00 p.m. There will, of course, be many other departing and arriving flights at LAX but certainly not more than 100 additional all cargo flights. If these flights are scheduled as shown in Figure 1.27, then no additional expansion of the airport capacity would be required. Similar consideration apply to other airports which would transport both passengers and freight.

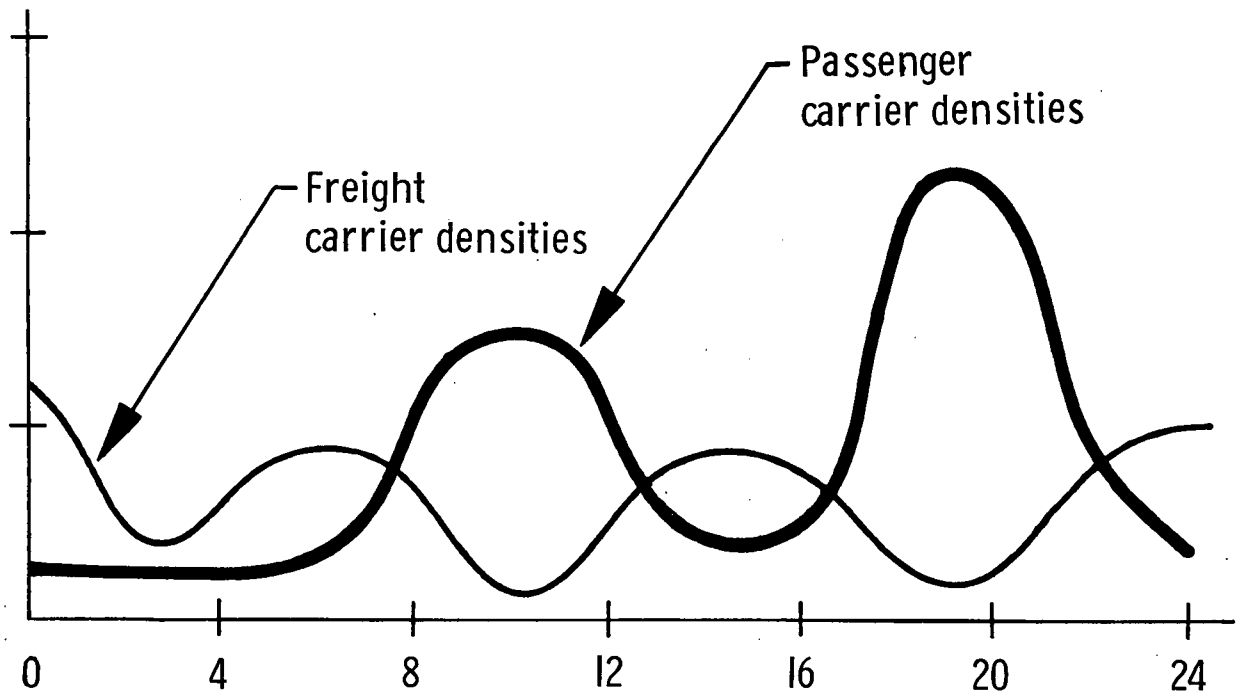


Figure 1.27 RELATIONSHIP OF PASSENGER CARRIER ARRIVAL AND DEPARTURE DENSITIES TO FREIGHT CARRIER ARRIVAL AND DEPARTURE DENSITIES

1.3 ECONOMICS OF NETWORKS

1.3.1. Factors Influencing the Economics of Networks

The number of parameters involved in the study of the economics of any transportation network is tremendous. To complicate the situation, many of the parameters are not independent; that is, changing one parameter to determine its influence on the network also automatically causes a change in some other parameter, thus disguising the desired results. Even so, studies in which parameter variations are made will indicate trends useful in network planning.

If the air cargo system is to offer door-to-door pickup and delivery using various modes of transportation, the following considerations might be included in an economic study. Some of these are much more influencial than others in determining the economic stability of the system.

a. Demand - The requirements for shipping cargo vary from season to season and from city pair to city pair, affecting service, rate structures, and transportation requirements.

b. Currency Value - The cost statistics for economic analyses will quite often be formulated over several years. Since the value of the dollar varies yearly, the figures must be weighted to allow comparability.

c. Mix of Transportation Modes - The number of vehicles making up each mode of transportation will influence frequency of service and scheduling as well as investment costs.

d. Route system - Terminal locations and the routes connecting them are of prime importance in cost analyses (See Section 1.2).

e. Frequency of Service - User demand and shipper rates will depend on how often a mode of transportation arrives at and departs from a terminal (See Section 1.2).

f. Freight Density for Each Mode of Transportation - All modes of transportation will have limits on shipments, both in volume and in weight, but different modes are affected in different ways by cargo density. Ideally, each shipment will have the optimal density for the mode used; actually, the loads will be either smaller, lighter, or both. Thus, the full potential of the transportation mode will not be utilized resulting in higher costs per unit volume or unit weight.

g. Types of Cargo - Certain cargo, such as hazardous materials, live animals, perishable goods, and outsized items may require special handling. This would warrant special rates.

h. The Backhaul Problem - This problem occurs when any container or mode of transportation is utilized for only one-half of a round trip (see Section 1.2).

i. Balance in the Use of the Modes of Transportation - Any program analyzing network economics must insure that vehicles in any transportation mode that arrive at a terminal also depart from that terminal.

j. Location of Consolidation and Break-Bulk Facilities - If these facilities are not located at the transportation terminals, additional links in the hub-spoke system must be added, thereby increasing costs and delays.

k. Reservations and Sales Costs - Selling and reserving space on a particular mode of transportation for special size or quantity shipments will be a part of the services offered.

l. Advertising and Publicity Costs - To encourage maximum utilization, businesses and the public will have to be made aware of the services rendered by the air cargo system.

m. Administrative Costs - These are the costs related to the personnel and equipment required to make the system function.

n. Transportation Rate Structure - Because of competition or its possible role as a public utility, the air cargo system may have rates established by federal regulation rather than by the free market system.

o. Investment Costs - These include the costs of the modes of transportation, the way, and supporting equipment.

p. Transportation Mode Operation Costs

1. Direct Operating Costs

(a) Fuel and oil
(b) Crew or operators
(c) Insurance
(d) Maintenance labor
(e) Maintenance material
(f) Maintenance burden
(g) Depreciation

2. Indirect Operating Costs

(a) Supporting equipment maintenance
(b) Supporting equipment maintenance burden
(c) Supporting equipment depreciation and amortization

q. Revenues - The total income from all sources must be accounted for if earnings are to be maximized.

r. Sub-optimal Performance - Weather or mechanical failures may force a cancellation of shipments or a change in schedules.

s. The Effect of Competition - Competition tends to force a reduction in rates and must be taken into account in forecasts.

t. The Atmosphere of Regulation - If the government controls rates and routes, a less cost effective system will result (See Section 3.2).

u. Shipment Priority - The inclusion of more than one shipment priority will add to the complexity of the system and thus raise costs.

1.3.2. Network Economic Optimization Models

The economic analysis of any type of air cargo network is an extensive problem. Add to this the network requirements of door-to-door pick-up and delivery and the problem is compounded further. The quantity of factors affecting costs is extensive and their level of influence varies from critical to almost negligibile.

Simple and complex computer programs have been written by airframe manufacturers, airlines, and government agencies to study network economics; all have their shortcomings. Primary among the problems of a program is the inability to place a correct, if any, value on time. Attempts have been made to equalibrate the value of time to the value of warehouse storage, duplicate inventories, depreciation and obsolescence, and tie-up of capital. Useful as this might be, it still fails to account for human desires and needs, particularly during emergency situations. At such times, the value placed on time may be so high that the cost of shipment, no matter by what means, will be negligible in comparison. While time obviously has value, that value varies widely and can be specified only for specific shipments under specific conditions.

The analytical and algorithmic methods used in determining the most cost effective network are generally classified as optimization and heuristic methods. These procedures may be used either to minimize costs or to maximize earnings. The latter effort is more extensive since earnings may be assumed to equal revenues less costs. Thus, to insure maximum earnings, costs must be minimized and revenues maximized. A brief description of several techniques follows.

The classical transportation problem: This type of linear network optimi-- zation is useful primarily for the planning of the physical network, i.e., route determination. Its goal is to minimize total transportation cost.

The mathematical description of this problem (ref. 29) is

$$\text{minimize} \quad \sum_{i=1}^{m} \sum_{j=1}^{n} c_{ij} \, x_{ij} \tag{1.4}$$

in which c_{ij} is the shipping cost per tonne from point i to point j and x_{ij} is the number of tonnes shipped from point i to point j. The model restrictions are stated as

$$\sum_{j=1}^{n} x_{ij} \leq S_i \qquad i = 1, 2, \ldots, m \tag{1.5}$$

indicating the supply limitations on the number of tonnes shipped,

$$\sum_{i=1}^{m} x_{ij} \geq D_i \qquad j = 1, 2, \ldots, n \tag{1.6}$$

indicating the demand limitations on the number of tonnes shipped, and

$$x_{ij} \geq 0 \qquad \text{for all i and j} \tag{1.7}$$

implying that no negative quantities may be shipped. If the total supply is at least as large as the total demand, it is always possible to find a feasible transportation network in which no more than (m + n-1) routes are utilized and an optimal solution in which no more than (m + n-1) routes are employed.

Application of this technique to the hub-spoke system proposed in Section 1.1 would be most beneficial to the pickup and distribution of freight in the spoke regions. The remaining network routes are established from the selection of hub and spoke terminals.

Linear programming: A combination of analytical and graphical procedures may be used to determine which modes of transportation should be used for the various links of the network as well as how long these links should be. The requirements for using this technique are that the equations of cost for the various modes of transportation be linear and constraints be indicated in the form of equalities or inequalities (ref. 30).

An example of the analysis of a hub-spoke system, based upon the central-place theory discussed in section 1.1, follows. In this example, the cost is minimized with respect to the distances through which the various modes of transportation will move the cargo. It is assumed that one unit of cargo, which is evenly distributed throughout the region served by hub A, is transported to the region served by hub B and evenly distributed throughout it (Fig. 1.28).

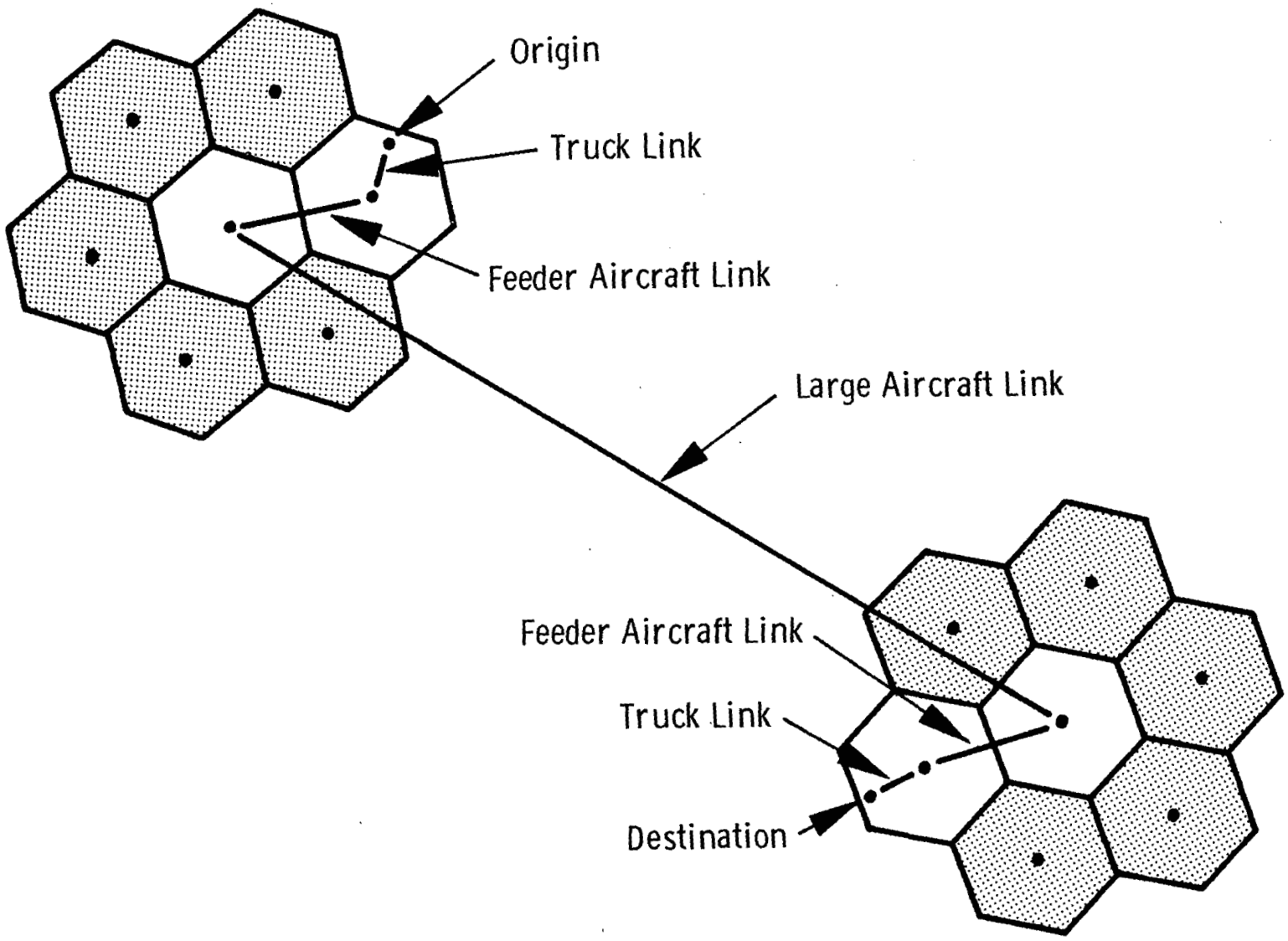


Figure 1.28 THEORETICAL HUB-SPOKE

Further restrictions or constraints include:

a. The pick-up and transport to a spoke terminal and the delivery from a spoke terminal to the destination is handled by truck. From the CLASS report (ref. 31), these vehicles have total operating costs given by

$$C_T = \frac{2}{25} R_T + 60 \tag{1.8}$$

where C_T is the cost of shipping by truck and R_T is the distance traveled. The maximum range is considered to be 550km (340mi). The constant (60 for truck) is the minimum fixed cost characteristic of a single trip by the vehicle.

b. The transportation between spoke and hub terminals is by intermediate-payload freight aircraft having a maximum range of 2400km (1500mi) and a cost curve estimated to be

$$C_F = \frac{4}{25} R_F + 170 \tag{1.9}$$

in which C_F is the cost of shipping by feeder aircraft and R_F is the distance traveled. The minimum range is assumed to be 1100km (685mi), an arbitrary choice determined by the point at which the line haul costs are equal to the sum of the remaining costs.

c. The transportation between hub terminals is by long-range, high-payload freight aircraft having a cost curve of (ref. 31)

$$C_L = \frac{3}{25} R_L + 170 \tag{1.10}$$

where C_L is the cost of shipping by long range aircraft and R_L is the distance of shipment. This aircraft is assumed to have a maximum range of 6400km (4000mi) and minimum range of 1400km (870mi), for the same reason as indicated for the feeder aircraft.

d. The total trip length is 8000km (5000mi).

These transportation costs and constraints may be stated analytically as

$$\text{total cost} = C = 2C_T + 2\left(\frac{6}{7}\right)^{*} C_F + C_L$$

$$= 2\left(\frac{2}{25} R_T + 60\right) + 2\left(\frac{6}{7}\right)\left(\frac{4}{25} R_F + 170\right) + \frac{3}{25} R_L + 170 \tag{1.11}$$

$$= \frac{4}{25} R_T + \frac{48}{175} R_F + \frac{3}{25} R_L + \frac{4070}{7} \tag{1.12}$$

subject to the constraints:

$$2R_T + 2R_F + R_L = 8000 \tag{1.13}$$

$$0 \leq R_T \leq 550 \tag{1.14}$$

$$1100 \leq R_F \leq 2400 \tag{1.15}$$

$$1400 \leq R_L \leq 6400 \tag{1.16}$$

Solving equation (1.13) for R_L and substituting into equation (1.12) yields

$$C = \frac{-2}{25} R_T + \frac{6}{175} R_F + \frac{10790}{7} \tag{1.17}$$

Since the cost is now expressed as a function of R_T and R_F, graphical procedures may be used to find the minimum cost, as illustrated in Figure 1.29.

The dashed lines representing solutions of constant cost, obtained from equation (1.17), indicate a minimum cost of \$1535.14, occurring when R_T = 550km (340mi), R_F = 1100km (685mi), and R_L = 4700km (2900mi). This solution is compatible with the hub-spoke system based upon the central-place theory.

If the same basic problem were solved with the constraints on the truck and feeder aircraft changed to

$$0 \leq R_T \leq 1000 \tag{1.18}$$

$$0 \leq R_F \leq 2400 \tag{1.19}$$

the minimum cost would be \$1461.43 occurring when R_T = 1000km (620mi), R_F = 0km, and R_L = 6000km (3700mi). The savings over the previous example would be \$73.71. This is only a 4.8% decrease in price in conjunction with a probable two-day delay in transit due to the elimination of the feeder aircraft as a mode of transportation and the lengthening of the truck link. Whitehead (ref. 24) obtained a similar result. Weakness in this model and Whitehead's is the failure to place a value on time.

*Only six of the seven hexagons in the hub region (See Fig. 1.26) are served by feeder aircraft.

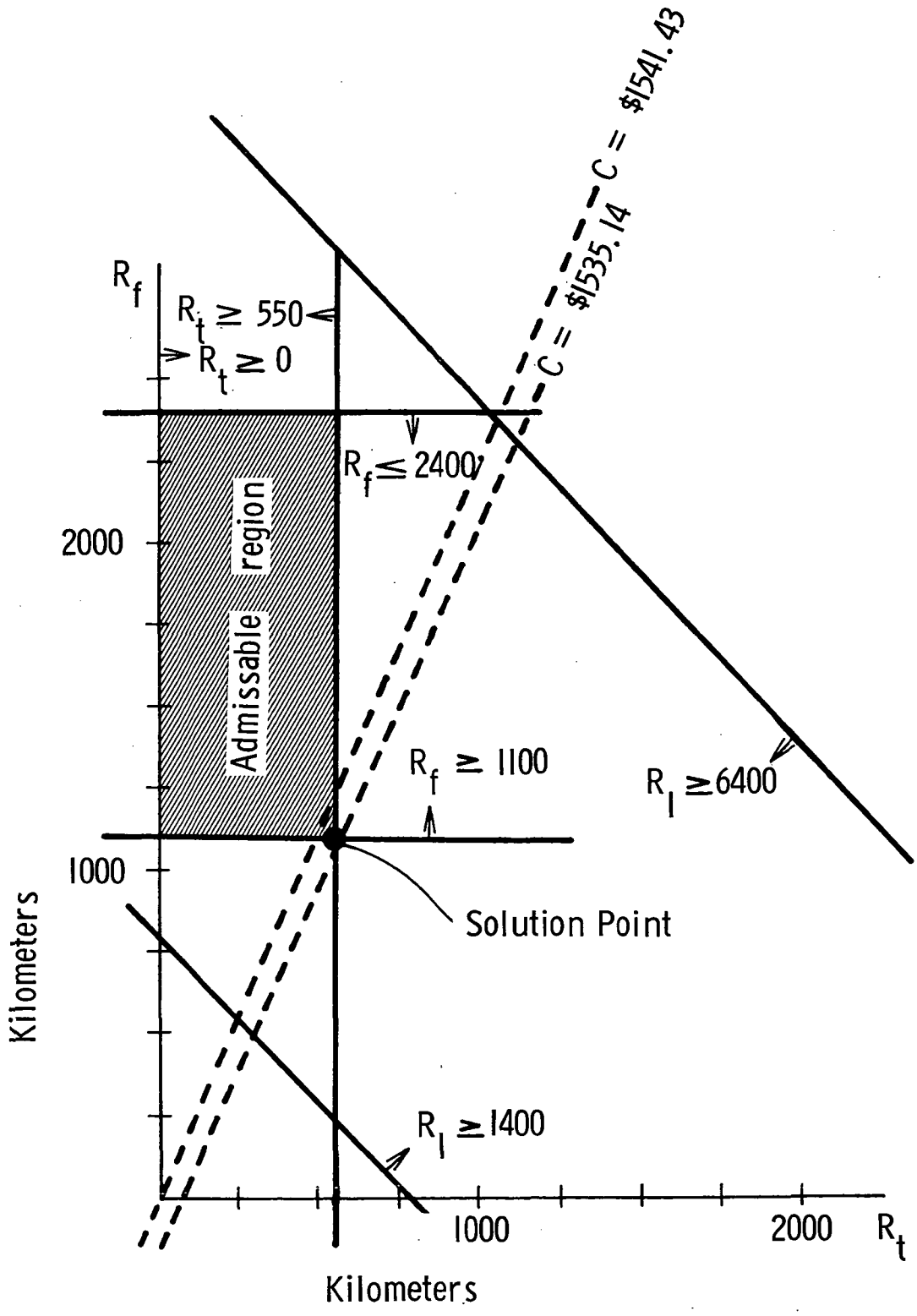


Figure 1.29 LINEAR PROGRAM SOLUTION

If an arbitrary value on time were set at \$480 per unit load per day, the shipping costs in the last example would rise by \$960 to \$2421.43. This is a 65% increase over the cost when the feeder aircraft is used and a 57.7% increase over the cost of the first linear programming example where the more restricted range constraints were imposed. Thus, the usefulness of assigning time a value is illustrated as is the need for feeder aircraft in the hub-spoke system.

A second approach to placing a value on time is to introduce a cost per unit time value into the cost equations for each mode of transportation. If this value were set at \$20 per unit load per hour, the equations of cost for the three modes of transportation would become

$$C_T = 20\left(\frac{1}{88.5}\right) R_T + \frac{2}{25} R_T + 60 \qquad (1.20)$$

in which 88.5 is the average speed in km/h (55mi/hr) for trucks,

$$C_F = 20\left(\frac{1}{885}\right) R_F + \frac{4}{25} R_F + 170 \qquad (1.21)$$

where 885 is the average speed in km/h (550mi/hr) of the feeder aircraft, and

$$C_L = 20\left(\frac{1}{950}\right) R_L + \frac{3}{25} R_L + 170 \qquad (1.22)$$

In this last equation, the 950 represents the average speed in km/h of the long haul aircraft (590mi/hr).

Substitution of equations (1.20), (1.21), and (1.22) into equation (1.11), using the constraints indicated in equations (1.13), (1.14), (1.18), and (1.19), and following the graphical procedures outlined above, yields a minimum cost of \$1734.23. This cost occurs when R_T = 0km, R_F = 800km (500mi), and R_L = 6400km (4000mi). This answer, though mathematically correct, is not realistic since it implies that every user will have a feeder aircraft airport at his door. Only by further constraining the minimum range of the feeder aircraft may this pitfall be avoided.

Modified forms of equations (1.20) and (1.21) may also be used to allow the shipper to determine how much his time must be worth to use both truck and feeder aircraft economically for either the first or last two links of the hub-spoke system, as opposed to use of truck only. For this method, the cost of truck transportation from origin to hub terminal (or from hub terminal to destination)

becomes

$$C_T = 60 + \left(\frac{2}{25} + \frac{C}{88.5}\right) D \tag{1.23}$$

in which C is the cost per unit load per hour, a variable, and D is the distance from origin to hub terminal (or hub terminal to destination), also a variable. The cost between the same points using both truck and feeder aircraft becomes

$$C_{T-F} = 170 + \left(\frac{4}{25} + \frac{C}{885}\right) (D - D_T) + 60 + \left(\frac{2}{25} + \frac{C}{88.5}\right) D_T \tag{1.24}$$

in which D_T is the distance from the point of origin to the spoke terminal (or from the spoke terminal to the destination). Equating (1.23) and (1.24) yields

$$-\frac{2D}{25} + \frac{9C \cdot D}{885} + \frac{2D_T}{25} - \frac{9C \cdot D_T}{885} = 170 \tag{1.25}$$

For each value of D_T (a parameter), a curve of distance from origin to hub terminal (or hub terminal to destination) versus cost per unit load per hour may be obtained, as shown in Figure 1.30. Thus, if a shipper is, for instance, 1000km (620mi) from the nearest hub terminal and is 300km (190mi) from the regional spoke terminal, his value on time must be at least $31.61 per unit load per hour before the use of feeder aircraft becomes economical. Values on time of less than $31.61 per unit load per hour indicate that only trucks should be used.

Gradient methods: Gradient methods or methods of steepest descent or ascent are numerical methods characterized by iterative algorithms for improving the estimates of independent variables so as to satisfy the condition for a maximum or minimum. A complete description is given by Bryson and Ho (ref. 30). These methods would allow an optimal solution if the cost functions for the various modes of transportation were nonlinear and the constraints of the problem were of the equality or inequality type.

1.3.4. Remarks

As has been implied previously, the trade-off between cost and time must constantly be remembered. Though the mathematics of the problem may indicate one solution, the value placed on time by the user of the system must not be forgotten. A theoretical model of a network may be suitable for initial studies, but the analysis of a specific network of routes and terminals and insertion of time cost values will yield more reliable data.

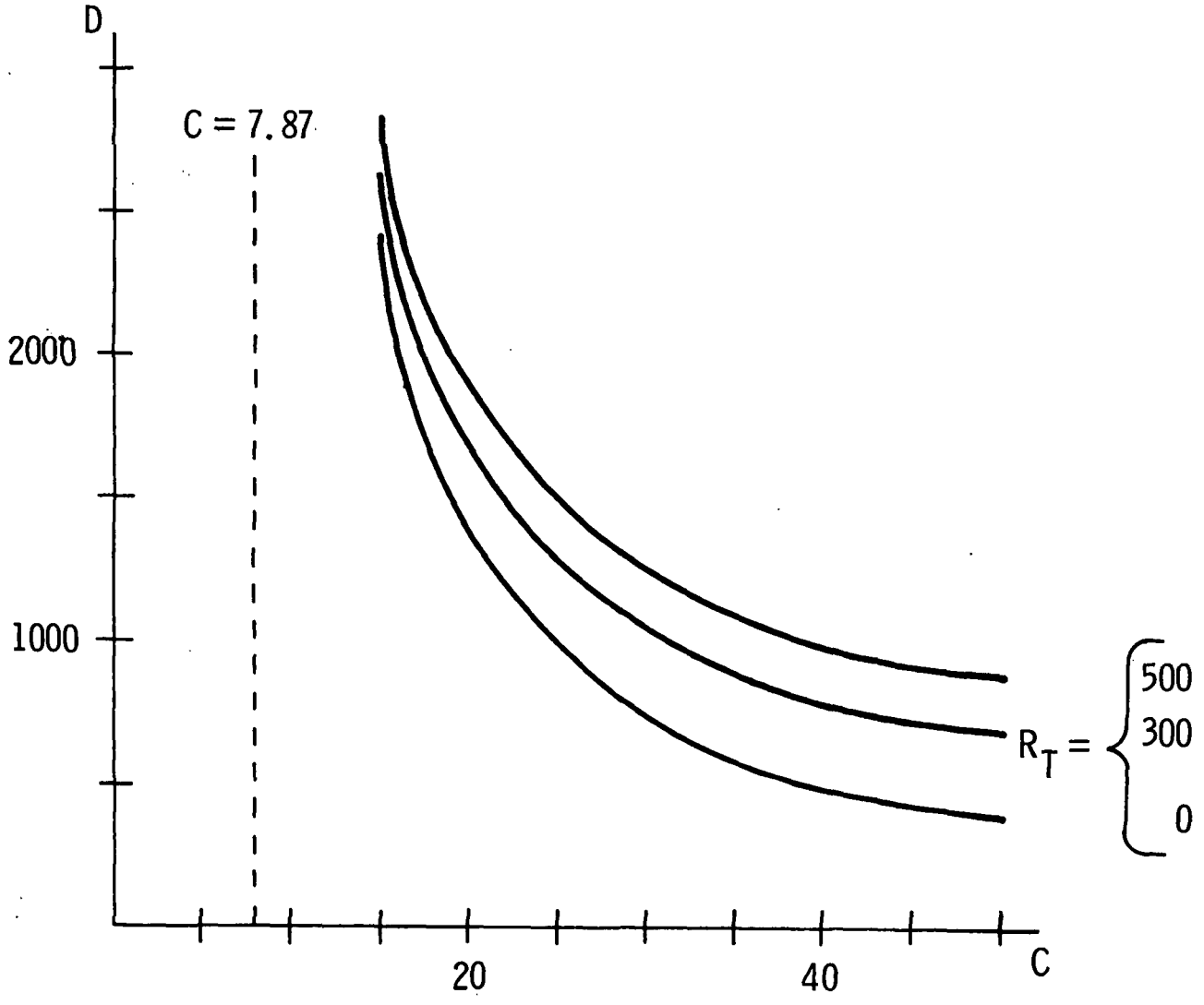


Figure 1.30 THE VALUE OF TIME PER UNIT LOAD PER HOUR

No matter how sophisticated, any economic model which uses the forecasts of future situations is susceptible to error. Major and occasionally minor errors in estimating future demands, capabilities, and operations could negate all results of an economic analysis. As a result, it is not unusual to find that "gut feelings" may reveal trends just as accurately as a complex computer program.

1.4 CURRENT CARGO CAPABILITY AND POTENTIAL

1.4.1. Existing Airports and a New System

A great deal of information on the cargo capabilities of existing airport facilities should be known before any attempt is made to select an optimal set of airports in any coordinated network of air freight delivery. Because they represent, largely, undeveloped regions of the country where expansion is possible and investments exist, the current and idle military air facilities could augment the generally more desirable but constricted civil airports.

Description of airport freight capacity is complicated by the fact that, except for military airfields, there is no airport cargo capacity, but rather a series of cargo capacities, one for each of the airlines or other freight forwarding firms located at the airport. At any one field, the various firms may be almost anywhere on the continuum from passenger service only, through small parcel and major belly cargo carriers, to freight-only firms. Large fields tend to have several large cargo firms, but some smaller firms as well. Smaller fields may be strategically located and have high cargo requirements or have none at all.

The amount of detail desirable for assessing the current and potential value of a given field in the overall air freight system depends also on the basic system philosophy. A few major hub freightports fed by truck have entirely different implications from a multihub system or one that uses a relatively large number of feeder airports with or without major freight hubs.

The network design assumptions may require, say, three U.S. hub air freightports. The constraints on airport capacity could conceivably rule out this design because the locations needed for efficiency could not be modified to handle the projected volume of cargo. An alternative might then be a point-to-point network made up of more feasible cargo capacities at a larger number of airports.

To allow for network design tradeoffs and contingencies, and for the selection of those best suited to the system requirements, an inventory of factors influencing freight capacity of existing air facilities is needed for a relatively large number of airports. No such inventory exists with the kinds of current, detailed description desirable. A preliminary version of a questionnaire which would collect these data is found in Appendix C of this report.

Even if all the desired information were available, of course, there is no authority which can suddenly impose a design on the providers of air service in the U.S. A new system must evolve from its current status to one which meets the needs of the changing world in terms of demand and economics. For a rough notion of the current cargo picture, some information on current airports

is given in Table 1.3.

Before the "ideal" system can be conceived, it is informative to examine the way the present needs are met. In this space age of pocket computers and automated Mars explorations, it may be surprising to discover that much of the air cargo is handled with little beyond 1950 technology. Newer planes are used, and the computer helps in the paperwork, but the progress of mechanization in moving goods has been modest. The next few pages describe what goes on today. After a brief status report, the operation in a moderate-sized airport is described in detail. While a few airports around the world handle much greater volumes, the total moved by all the moderate-sized airports is what makes the whole system work and gives potential for the future.

A brief look at a proposed military air cargo terminal is given next for possible insight. This is followed by a look at what many might have expected was typical -- automatic container handling and storage at a major airport. This section concludes with a discussion of the direction in which our current system is likely to go. The forces which mold evolutionary change are not likely to change in the near future. They include occasional step-wise improvements but are more often incremental improvements on current conditions until fundamental changes are forced on the system. These changes are triggered by growing inefficiencies or daring innovators who threaten the status quo.

1.4.2. Today's "Non-System" of Cargo Service

The U.S. Airlines, all carrying some kind of cargo, operate about 13 000 scheduled flights daily. This amounts to 20 million freight shipments annually involving 600 American airports and 100 foreign airports. In the U.S., over 10 000 communities are served by truck and air. Air freight totals about 3.3 million tons a year, half of it in all-cargo aircraft, the other half in the bellies of B-747, DC-10, and L-1011 passenger aircraft.

The problems in the use of air for cargo arise in the lack of convenient point-to-point delivery service. Brochures discuss the service provided by "some airlines" (ref. 32) but not all. "Often, there are signs at the airport directing shippers to the ticket counters accepting the small packages," but usually not; some charge "a flat fee to move a package anywhere in its system," according to the brochures, others charge according to route segment; pick up or delivery can be arranged by "some airlines" and "there are some provisions for interlining" (pre-arranged transfers among two or more airlines). The exceptions make the system most useful for exchange between major population centers and for emergency shipments where the complexity is acceptable because of urgent need for speed.

Through an organization called Air Cargo, Inc., air carriers in North America have developed a fairly widespread system of delivery by air and truck to small communities. A bi-monthly directory listing these thousands of cities is available. There are 32 certified airlines, 160 motor carriers, and 30 commuter airlines participating in the Air/Truck Programs. Speed and reliability, as well as cost, are likely to vary widely in such a conglomerate which lacks integral coordination of operations.

In contrast, Federal Express Corporation (FEC) was organized in 1973 to offer the same kind of service where speed and reliability of delivery for small packages was the main objective. This single organization of trucks and small aircraft with highly flexible and efficient routing and mostly night flights allows service not possible in a multi-firm cooperative effort. For small shipments (up to 70lb, routinely), FEC has a near monopoly on point-to-point delivery over much of the U.S. Many small communities continue to lack service, but an expanding air cargo demand demonstrates the need for a system. The $50 million initial capital investment - the largest ever arranged in the U.S. - created a system which started from nothing and turned a profit in only two years. There is little chance that a direct competitor will appear in this market;, however, the system of heavy routine and emergency shipments in which air freight is economically feasible constitutes a separate, complementary market which is now being served to some extent but is not being developed to anywhere near its potential.

For efficiency with larger volumes of air cargo, containerization must eventually be developed. This requires not minor improvements, but revolutionary redesigns in facilities and large investments. Whether individual airlines can continue (or will decide to) make these investments or consolidate into airport-wide cargo systems is yet to be decided.

1.4.3. The Air Cargo Complex at Baltimore-Washington International Airport (BWI)

There are 15 certified airlines now serving the cargo needs at BWI and several more are expected in the next few months. Only 25 airports in America have more than BWI (See Table 1.3). It also has 26 air forwarders serving it and only 11 airports exceed this number. This makes BWI a "large" airport, probably typical of the major feeder airports which would make up any future organized cargo network. It is enlightening to discover how freight is now being handled at such a "major feeder".

As in any civilian air terminal, there is really no airport cargo handling system, but only a series of separate, widely divergent airline cargo systems which represent the present cargo shipping practice. The cargo complex at BWI consists of three buildings which are essentially back-to-back docks with a small floor space between them. Trucks back up to one side and unload and, after a sorting process, other trucks back up to the other side to deliver freight to the airlines or airplanes. All packages are in and out in a matter of a few hours, often a few minutes. While there is the usual series of small cargo facilities or offices for each air carrier, separate buildings are used by three major cargo carriers.

In addition to the 15 scheduled cargo-hauling air carriers now serving BWI, several major and smaller freight carriers are said to be considering locating there (ref. 33). These include Iberia, Lufthansa, KLM, Flying Tiger, and others. Piedmont recently moved its entire operation there, and North Central Airlines moved there in August 1978.

The runways at BWI are capable of handling all aircraft including the C-5A which has landed there, but the Concorde and the DC-8-61, for example, should have longer runways for routine operations which involve maximum loads and all weather conditions.

BWI is about fourth in U.S. air freight growth rate, but there are problems in ranking airports. For example, BWI, with 20 795tonnes (22 923tons) of freight enplaned in 1977, ranks about 20th. Yet the freight deplaned at BWI was almost twice as much, 38 570tonnes (42 520tons), and another 20 300tonnes (22 375tons) of mail was enplaned or deplaned (almost equally) in 1977. For capacity analyses, it could be argued that the ranking should be based on the sum of the larger of the cargo enplaned or deplaned plus the larger of the mail enplaned or deplaned. This is more closely related to current operating capacity than other combinations of these figures. Since some airports have greater incoming loads than outgoing loads and others are the opposite, neither figure can be used for overall comparisons. In the same way, totals of incoming and outgoing freight are misleading since an even balance is more efficiently accommodated than unbalanced cargo flows, so a freight flow of 50 units in and 50 units out probably requires less investment and staff than one with 70 units in and 30 units out, even though the total freight handled is 100 units in each case.

National Airport near Washington, D.C., will have a curfew imposed soon, according to its operator, the Federal Aviation Administration. This will tend to make air cargo firms shift to BWI. Several firms have indicated they will make this move, and BWI expects to double cargo volumes in the next few years. Deep water containership ports are 8 to 10 miles away, Conrail comes near a current runway terminus, and the interstate system is easily accessible, making a truly multimodal operation possible. However, airline marketing efforts, with a few exceptions, show little expertise in cargo handling or knowing the customer's needs. The air forwarders are now the biggest customer of the airlines, doing the marketing for them. The forwarders, if they buy planes, could become the biggest competition of airlines. This fact seems to have aroused little anxiety among airline executives.

At BWI, United Airlines Cargo system is the largest of the cargo carriers, and the only one with regular air freighter aircraft. BWI is a major truck terminus for United, gathering freight from Philadelphia, Washington, Norfolk, and Richmond areas since none of these has air freighter service. Two DC-8 freighters leave BWI at 12:30 a.m. and 02:20 a.m. Tuesday through Saturday. Other freight is sent by belly cargo in B-737, B-727, and DC-10 (widebody) passenger flights with belly cargo during the daytime, depending on destination, schedules, and expected freight volumes. The decision as to which plane will carry a package is largely dependent on the cargo agent's knowledge of flight alternatives, rather than a formal routing or decision system. Presumably poorly routed packages would not result in feedback to this agent unless a serious (to the shipper) delay resulted. This system also implies that different agents often make different judgments. While actual routes are documented after a decision for tracing, it seems likely that improvements could be made if it were shown to be desirable.

Cargo can arrive almost anytime of the day or night at the terminal, though the bulk arrives after 4 p.m. and continues to come in until after 11 p.m. About 10 p.m., the container filling begins, with men obtaining empty containers from the storage area outside the plane docks, and moving them in on dollies either by hand or by electric truck. Freight from pallets or loose boxes and crates are stuffed into the containers. Heavy items are moved by forklift truck, but most packages are manually arranged in the containers for the main deck of the DC-8, or the various LD (lower deck) shaped containers for use in the B-747 or DC-10 bellies. This requires the loaders to climb into the container to fill the volumes as they see fit. Each container is loaded with material for one ultimate or intermediate destination.

As each item arrives at the cargo terminal, an airbill is made out showing origin, destination, contents, number of items, weights, and airbill number. Copies of this airbill are attached to the package in an adhesive envelope. As the pallet or container is filled (unitized), the airbill numbers and weights are written on a sheet which will be placed in a cargo pallet tag (envelope) which is attached to the outside of the container with a wire twist. As containers are made up, the content lists are sent to a weight and balance agent who must that the aircraft will bly well as loaded and that the total weight is not excessive. It is usually the volume rather than the weight capacity that limits the load. About 240kg/m^3 (15lb/ft^3) density would be required for just filling both weight and volume limits, and freight often average less than 160kg/m^3 (10lb/ft^3). With the loss of useable volume in the aircraft and empty spaces in containers, the density may drop even further, to 96kg/m^3 (6lb/ft^3) perhaps.

As containers are filled, the order of aircraft loading is determined for weight and balance purposes, and the containers are staged for loading. A mechanized system allows a pallet or container with its dolly to drop into a pit for loading. This pit is also used to fit the cargo nets over pallets for securing the loads. One or two filled units are placed on each of nine motorized roller tables. When the plane is ready, the elevator loader is moved into position at the plane's cargo door and a loader vehicle shuttles each container to the elevator in the required order. The loader vehicle is driven up to one of the nine staging lines, the operator reaches out of the cab window and pushes a button on a switchbox suspended conveniently from a cable. This moves a container to the loader, which is then turned around and driven to the lowered elevator. The container is moved electrically on to the elevator; it is raised, after which the container moves forward to the plane-level platform. The elevator can then be lowered ready for the next container while the one just delivered is moved into the plane and pushed manually into its assigned position. A round trip by the vehicle takes less than 30 seconds.

While the containers are being loaded, electric carts have been busy hauling loose cargo and mail sacks to the fore and aft belly compartments. As the total load becomes known, the pilot may decide to add fuel since the load is estimated, often quite inaccurately, prior to receiving all the outgoing cargo. Fuel is taken on for the estimated load, but excess fuel weight is avoided for economy. The entire loading and aircraft checkout process requires about 30 minutes after the containers are ready. Some containers for other

flights may be moved to the passenger aircraft belly loading areas at any timas well.

Meanwhile, documentation is proceeding in the office and in the cargo area. Information from the airbill is entered into a computer display system for tracing each item. Its location and schedule can be called up in any of United's cargo offices, and the delays in entering information are short since the work progresses as freight is containerized and during loading. The information is transferred manually several times for making up the containers, for the pilot's manifest and the weight and balance calculation, for container labeling, and for the tracing and billing system. Recording errors are fairly common, but redundancies allow resolution with little delay in most cases. Where there are several pieces in one shipment, a stencil is cut and each carton is printed with a hand-held inking device.

One is impressed with the apparent confusion during the loading period and the apparently successful sorting, routing, billing, handling, timing, and packing decisions which must be coordinated in the process. Little mechanization is involved. Staff experience is obviously crucial, though the computerized information on routes, loads, United's office hours around the world, transfer points, other airlines' schedules, customer identification and needs, cargo type, special handling, etc, helps. The staff must keep track of perishable items in the cool ($4^{0}C$ or $40^{0}F$) room, live animals and pets, dry ice shipments (which cannot be in the same airplane compartment with animals because of the suffocating carbon dioxide it gives off), hazardous materials, and other special considerations.

Although the operation is very uneven, the area is very busy during the loading of an aircraft so this terminal seems to be working close to its practical capacity. Another plane perhaps could be handled if scheduling were convenient, and if more passenger aircraft belly volume were to be moved, but a large increase in freight volume could easily swamp the present system. More staff would probably not help much because of the increased coordination that it would entail. A larger aircraft would tax the staging area and slow the loading process. It might also require new containers which could make some of the handling equipment useless. The decision and documentation phases would undoubtably suffer seriously. These are the kinds of problems which must be faced before a larger air cargo business can be handled. The larger air freight systems are essentially different, not only in scale but also in kind.

1.4.4. Military Air Cargo

Military Needs: Military air cargo needs are different from civilian needs in several important aspects. First is cost: the military must deliver to a wide variety and quality of airfields on short notice and must unload without specialized ground equipment. The cost of providing such versatile designs is high and generally not feasible in a profit-making operation.

Air freighters similar to the C-130, C-141, and C-5A were designed for freight use with a high wing and "kneeling" landing gear so that the cargo doors could be near ground level. Lower ramps and loaders are simpler and can be carried in the aircraft or built into it without large weight penalties. Nose or tail doors allow vehicles to drive in (or through), and long loads or other oversize cargo which could not fit in side doors can be accommodated. The rear door also allows military cargo drop by parachutes.

In contrast, the B-747F and B-747C have nose doors but not tail doors, and the doorsills are 4.9m (16ft) above the ground. The standard Air Force 436L system 40K Loader can reach a height of about 3.7m (12ft), sufficient for loading the biggest military aircraft, the C-5A; however, a 1.2m (4ft) adapter platform must be placed under the 40K loader in order to load B-747F/C. A second 25K Loader is used to shuttle cargo from the assembly area to the 40K Loader on the platform, which lifts the freight to the nose door level.

A second area of difference in military cargo needs is related to load density. The C-5A is designed to carry tracked vehicles and the battle tank (M-60). It thus has a much stronger floor than the 747F. Density of air cargo in commercial transportation averages well under that required to make use of the maximum lift available. Containers use (and waste) more space, so that the 747F with 2.44m x 4.90m (8ft x 16ft) crossection plus lower deck for LD containers, and the proposed "lifted" version with two 2.4m x 4.9m (8ft x 16ft) decks, are more efficient for a system based on the standard intermodal container, than the C-5A which measures 4.0m (13ft) high and 4.9m (16ft) wide in one large cabin.

A military cargo system called the 453L is based on the 2.24m x 2.74m (88in x 108in) pallet loaded up to 2.44m (96in) high or 4750kg (10 500lb). This is different from the "Igloo" commercial container and from the ISO containers, so that there is little hope of an efficient interchange of cargo or cargo capability between the current military system and the proposed integrated cargo system.

Military Air Cargo Facilities: The need is greater to standardize material and units in a world-wide military operation than in civilian operation because of the single source of supply and critical planning requirements. It is also more feasible, since there is one overall authority. The Air Force cargo system, while it is based on a pallet size which is not compatible with the ISO intermodal container, is based on one standard, so the handling concepts are, in theory, transferable. In fact, however, the military cargo systems have different demands, routes, and schedules. They are not especially efficient in the terms important to commercial users because of the costs, peak needs, and lack of established routine operations.

A new U.S. Navy Air Freight Terminal Facility, which might offer ideas for terminal design, is being developed for the Naval Air Station (NAS) in Norfolk, Virginia. A concept study (ref. 34) determined that a gross area of 5700m^2 (61 000ft^2) at a cost of about $3 million would be appropriate. However, the best concept was relatively unsophisticated, at least compared to the Lufthansa operation in New York, which will be discussed in Section 1.4.5. It

will be more like the United Airlines cargo operation in Baltimore (BWI). The NAS terminal is to have six originating and seven terminating truck docks and 21 docking positions for K-loaders, each with a pallet conveyor. Up to 100 pallets can be on conveyors, and any pallet can be moved to another conveyor station by means of a motor transfer cart, manually controlled. Maximum design volume is 180tonnes (200tons) per day, one-third of which is terminating at NAS. There are spaces for customs and for refrigerated and hazardous materials. A staff of 50 can be accommodated.

While this new design for NAS may be advanced in terms of the systems used in the military and may meet their needs very well, it does not provide the kind of innovation necessary for a high-volume containerized cargo operation. The forklift truck, an integral part of the NAS concept, is limited in container handling because of size, weights, and damage potential. While the forklift will continue to be used in the loading of each container, the containers themselves need more efficient means for guiding their movements and for documenting the contents.

1.4.5. An Example of Containerized Freight Movement

In contrast to the great majority of current cargo handling techniques, there are a few operations which are now capable of handling cargo in the manner envisioned for the nodes of an integrated cargo system, in which a small number of standard container types are handled routinely. One major problem in the growth of this capability is the intermodal character of the containers. The intermodal-ocean container began with the Sea-Land operations in 1956. By 1968, despite widespread predictions to the contrary, over 100 vessel companies were involved. Containers became more popular, and by 1976 there were 1.6 million 6.1m (20ft) ISO container equivalents in service (ref. 35).

The sea-going containers are stacked six high in the hold and extend above the main deck of the containership. This requires a strong, and thus heavy, box which is costly to move by air. Even though the container could weigh almost as much as the cargo without overtaxing the lift capacity in today's low density air cargo, the added weight does increase fuel costs.

A lighter intermodal-air container has been in use since 1975. It can be stacked only two high, which limits its use in ships. Nevertheless, 380 of them are in use in 1978, and 800 are projected by 1980.

Aircraft now available to handle the ISO containers include 58 B-747's with main deck cargo capability delivered in mid 1978 and in service with 26 operators. Of these, about 36 are cargo-only aircraft. The B-747 is now serving the continental U.S. and 32 other airports around the world. Table 1.5 lists the carriers flying cargo versions of the B-747 at this time (see also Table 1.2).

In 1973, Lufthansa (ref. 28) became the first to carry ISO standard containers in B-747 aircraft in regular service. The Frankfort to Kennedy (NYC) service required a considerable investment in handling equipment and facilities.

Table 1.5

CARRIERS FLYING B-747 AIRCRAFT IN U.S., 1978

Rev**	Code	Airline
8	AA*	American Airlines
14	AC	Air Canada
6	AF*	Air France
-	AI	Air India
15	AZ	Alitalia
11	BA	British Airways
-	BN	Braniff International Airways
-	CP	CP Air
3	FT*	Flying Tiger
-	IB	Iberia
7	JL*	Japan Air Lines
-	KE	Korean Airways
12	KL	KLM-Royal Dutch Airlines
4	LH*	Lufthansa German Airlines
-	LY*	El Al Israel Airlines
10	NW*	Northwest Orient Airline
-	OA	Olympic Airways
2	PA*	Pan American World Airways
-	QF	Quantas Airways
13	SB*	Seaboard World
-	SK	SAS - Scandinavian Airlines
-	SN	Sabena-Belgian Airlines
-	TP	TAP
9	TW	Trans World Airlines
5	UA	United Airlines

* All-cargo versions B-747 are used by this airline. Cargolux, Iraqi, and World lines also have them.
** World rank in revenue ton-miles for cargo, 1976. Aeroflot is number 1. (Ref. 46, 48).

The 9000m^2 (97 000ft^2) terminal at NYC cost $16.2 million. However, it requires only 45 minutes from the opening to the closing of the nose door to remove and replace about 90tonnes (100tons) of freight in a load of 28 containers, each 3.05m (10ft) long. These are handled on a regular six-day per week basis. A computer-controlled oversize storage machine handles ISO containers, igloos, and various pallets in its 227 storage openings which rise to 15m (50ft) above the floor. All transfers are powered, and transfer platforms can raise and tilt to mate with the aircraft doors and floors, though the telescoping dock never actually touches the relatively delicate aircraft nose structure.

Each freight unit is numbered. The transfer platform operator enters the numbers via an on-board CRT terminal for storage and the various transfer operations which the computer controls. Containers are emptied and sorting is done with the machine serving as a transfer cart to tow carts and work stations. Five conveyors at the work stations transfer material to or from the 26 truck docks via tow carts. On command, the carts move to customs or truck docks with the destination determined by mechanical probes which are read automatically. Full containers or those too large for tow carts are forklifted directly to the heavy storage areas.

Entering freight from trucks goes by roller-bed truck to container storage or to work stations for containerization and then to storage. Cart numbers and cargo identification are assigned by the dispatcher from the airbill. A photoscanner reads cart numbers for controlling their movements by computer.

The DEC single-process computer takes inputs from optical scanners and load sensors and from various operators in the terminal. As a cart leaves storage, the computer prints out the previous cart's destination, so the operator can manually set the mechanical probes for the next destination. The computer keeps track of the contents of the storage area, the airbill numbers of the contents, the total inventory, status reports on loading and load staging operations, and other routine information, as well as controlling the movements of the carts and the storage machine. Two CRT terminals, five teletype units, and a telephone net complete the system.

Lufthansa ranked fourth in world cargo revenue ton-miles in 1976 (See Table 1.4), and now (ref. 36) flies two B-747F and six B-747-200B combination aircraft. The utilization of specialized, computer-controlled systems is thus not yet very intensive, though Lufthansa also flies the same aircraft to Boston, Philadelphia, Chicago, Los Angeles, and Amsterdam. Growth, based on the experience of mechanized container operations such as Lufthansa's, is needed before a world-wide air cargo system can be said to exist. In 1977, there were 115 all-cargo (including 14 widebody B-747F) aircraft, 303 other widebody combination aircraft, and 1842 other combination aircraft being flown by U.S. scheduled airlines. The all-cargo aircraft served 49 airports and the widebody combination aircraft served 53. Of the 631 airports served in the U.S., with their 1007 airline operations facilities, 702 freight operations areas were maintained separately from passenger facilities. Only 3 were reported which had off-airport freight facilities. In 1976, only 6.7% of freight shipments were containerized by the shippers, though 17.7% of all freight volume was shipped in containers. As mentioned before, the load

factors were not especially good, with 50-60% usual and an occasional 70% seen (ref. 37).

1.4.6. Potential and Problems in Expansion of Air Cargo Business

While growth in air cargo demand has not been as rapid as most of the predictions of the past few years, the potential continues to exist as demonstrated by the fantastic growth of firms such as Federal Express, Burlington Northern Air Freight, and many other freight forwarders. Where new service is provided, the demand seems to be generated.

A basic problem in expansion of air cargo capability is the capital which must be risked on the promise of new business. Federal Express Corporation needed $50 million before one cent of revenue was received. Lufthansa invested $16.2 million in the New York facility alone in order to handle intermodal containers more efficiently, and similar investments will be needed in Frankfort, Amsterdam, Bogata, Boston, Philadelphia, Chicago, Los Angeles, and other major terminals if the system is to be fully exploited.

This kind of investment and the innovation which results in rapid growth is not typical of the passenger-oriented major airlines. On the other hand, according to one airport cargo manager, Seaboard World Airlines has a facility in which a B-747F can have its belly compartments being loaded, its nose and side door in use unloading the main deck, and an engine being changed, simultaneously, in one large building. Innovation has its risks, of course, and Seaboard apparently had an automated tow-cart system with drag cables in the floor which did not prove practical and had to be abandoned. There have been other failures in automation, where reliability or cost were not controllable or the real needs of the system were not being met, either initially or as the conditions changed with time.

Cargo handling and loading is widely recognized as a bottleneck area which limits the productivity of air shipping. As in all production systems, the decision to remain manual or to automate depends largely on volume or throughput. Expansion is possible only to a degree, after which automated approaches are necessary for both capacity and efficiency. Given a current capacity of 100%, improvements, more staff, and greater stresses can result in larger throughputs, perhaps to 140% or 160%. Further increases can be gained only by a change in the system: larger, automated facilities provide, in one step, perhaps a 300-500% capacity increase. Some of this new capacity will go unused for a time resulting in higher unit cost, but none of the new capacity is available without a large investment, risk, and disruption of current methods.

Improvements in loading are illustrated by the various methods used in main deck loading of the DC-10F. An on-board loader is available which can load or unload the aircraft in 137 minutes (ref. 37). This can be speeded up to 93 minutes by use of a light-lift forktruck. If specialized mobile or transporter loaders are available, the time can be cut further to 64 minutes or 50% of the original. However, a loading dock which allows direct transfer from a dock into the aircraft main deck can reduce this time to 48 minutes or

34% of the original. This requires the cost of mechanization to a narrower range of equipment and of specific aircraft taxiing and parking requirements.

Loading and handling technique, of course, is primarily dependent on the container or mix of containers involved. Where aircraft which take the large intermodal air freight containers are in use (see Table 1.2), specialized equipment is necessary and feasible. Improvements are being made in transporters, A-frame cranes, elevator-conveyor-ramps, computer-controlled movements, etc., and the number of lift-transfer-slide operations is being reduced for any one container as standardization becomes routine. On-board ramps and lifts require weight and design sophistication that are justifiable only for military needs. Duplication of cargo handling equipment at a large number of freightports also requires a larger investment as the sophistication of the techniques increases and makes the greatest possible standardization and interchangeability of equipment desirable.

Alternatives can be devised for many of the methods now in use, though a distinction must be retained between the freight facilities handling large containers and those handling belly types or bulk. For example, in main deck loading of aircraft like the B-747F, it is possible to raise each container to the nose door 4.9m (16ft) above the ground or to build the container handling equipment to deliver units at that level. The high dock not only is a potential safety hazard, but the availability of an aircraft like the lower L-500 would make such a high dock unnecessary and even unuseable. An aircraft elevator, designed to support the landing gear, may be more practical than the mechanism for a variable height output from an automated system handling long, heavy containers full of fragile materials. The engineering of elevators is a more routine process than the design of handling equipment, and the flexibility for aircraft types is retained. The rear-loading aircraft would still present a problem with tail clearance, however.

1.5 INTERMODAL TRANSFER

1.5.1. Transmodal Movements and Multimodal Systems (Adapted from ref. 5)

Throughout this report, the assumption is implicit that well integrated transportation systems with good methods for intermodal transfer would make it possible to use each mode optimally. For each transportation mode there are sets of circumstances under which it is superior to the alternatives. When a mode is used under less favorable conditions, it is less satisfactory in some sense than an alternative. Where a movement of either people or goods has some portion of the journey outside the optimal "window" of the selected mode, then a transfer to the optimal mode is suggested. Whether such multimodal movement is executed depends on whether the cost of transfer is less than the additional cost of operating suboptimally for a portion of the journey. The word cost here refers to costs of all kinds including time value for the cargo involved.

This line of reasoning suggests that the performance at the node or connection between two or more transportation modes is an important determinant of the degree of network optimization that is possible. In general, the performance at the connection points is the weakest link today for reasons that are perhaps more institutional than technical.

There are two aspects to transfer terminal (nodal) performance. The first is the transfer facility itself, its efficiency, safety, and amenities. The second is how long a person or cargo has to wait for the next process or the next vehicle that is to move it. Terminal performance largely determines link performance. How long a person or shipment spends in the terminal also is a function of the frequency of service and the scheduling on the links. A large part of what appears to be an inordinate amount of time cargo spends in terminals may be less dependent on design or efficiency, than on the scheduling and size of the vehicles. Further, the average speed of the links is a function of how long the vehicle is stopped at the terminal to load and unload, which is a function of terminal efficiency.

Another determinant of the degree of network optimization possible is the magnitude of the difference in the cost and performance of one mode and that of the next best alternative. For example, if long haul air is already marginally superior to long haul truck, there is no incentive for large investments in fast, efficient terminal transfer terminals. Only the promise of substantially superior air performance would provide that incentive.

Our transportation system has evolved with each mode operating essentially independently. Each mode attempts to serve as large a market as it can. This places a premium on versatility, a preference for a wide window of "not too bad" performance rather than a narrower window of superior performance. This blind competition is a disincentive to developing a good intermodal transfer capability.

Thus, the penalty the nation pays for poor intermodal transfer goes beyond the currently perceived costs and inconvenience; it has also been an inhibitor of maximizing the potential of the individual modes.

This observation implies that there is a cyclic aspect in moving toward truly multimodal networks: Current modal design and operation tends to even up the levels of performance among alternatives and decreases the incentive for building good intermodal transfer facilities. In turn, the absence of such facilities inhibits the narrowing of modal service for more efficient operation and thereby decreases the efficiency of that mode.

This suboptimization of each mode rather than the optimization of a multimodal network is largely the result of the lack of overall organization. If multimodal transportation companies or consortia were permitted and encouraged, the perceived incentives would shift toward network optimization. There are also potential disbenefits to permitting such organization. The various existing interests deserve careful attention, but the potential efficiencies and national benefits of an optimal network also deserve consideration.

1.5.2. Progress in Intermodality

The advanced cargo system is designed to provide mass air movements on routine schedules based on the needs of large-volume shippers. Small-volume shippers will have their packages consolidated into containerized lots, after which the shipments will follow the same procedures as larger shipments.

The NASA-Lockheed "Cargo/Logistics Airlift Systems Study (CLASS)" (ref. 49) describes the future air cargo transportation scenario as a coordinated surface-to-air-to-surface operation. The motor carrier industry will perform connecting services between units of the air mode as well as direct service and connecting services with rail and water transport. The air phase will have full intermodal compatibility with the surface transportation modes. A family of all-mode cargo load devices will have been developed for both air and surface use. The load devices will not be captive of any single mode but will be covered by equipment interchange agreements on all domestic and international routes. The system will handle shipment to be packed in truck-load or container-load lots by shippers, forwarders, and surface carriers.

Unitized loads will be trucked to and from airport centers for distances up to several hundred miles. In the "Summary Report on Intermodal Cargo Tests" (Project INTACT) by Lockheed-Georgia (ref. 38), it is shown that large all-cargo aircraft can be designed and operated so that direct operating costs will be low enough to provide attractive freight economics relative to surface transportation. The analyses also conclude that the present system of air movement of small shipments will not develop to a point where the productivity of a fleet of large cargo planes would be utilized effectively. Four observations that support this conclusion are;

(1) Small packages and emergency shipments will not provide sufficient volume to justify a fleet of large cargo aircraft.

(2) Large cargo aircraft require large unit cargo loads for high overall efficiency.

(3) The cost of handling individual shipments can be reduced through an optimized cargo unitization system with compatibility between the internal dimensions of the aircraft and the external dimensions of the unitized cargo.

(4) Large unit loads must be truly intermodal for direct interchange with surface transportation. The motor carrier is the way to optimize most of the interchange between the modes.

In terms of customer service, the present mode of air service, which is primarily small package emergency service, is now approaching maturity. This air cargo service does meet the needs of small shippers and will continue to do so. However, it does not nearly meet the needs of large shippers with routine volume shipments. Achievement of a viable large-volume air cargo service will depend on the following:

(1) Use of large containers that can be filled by shippers, surface carriers, or forwarders at off-airport sites.

(2) Complete compatibility with the surface freight systems to allow efficient ground interface and connecting service for onward freight movements.

(3) Cargo airplanes designed specifically for freight service and uncompromised by passenger considerations.

1.5.3. The Intermodal Aircraft

For good intermodal transfer, the ideal air freighter would have these characteristics:

(1) Cargo compartments and doors located and of such dimensions that speed in loading and unloading are facilitated.

(2) Height of sill (distance between ground and bottom of cargo door) compatible with other modes of transportation or standardized for loading equipment compatibility.

(3) Dimensions of cargo compartments and doors large enough to accommodate all standard containers.

In general, the ideal air freighter would have cargo doors to allow nose or tail loading (preferably both), compartments large enough to receive and secure a 2.44m x 2.44m x 12.19m (8ft x 8ft x 40ft) container, height to sill of 1 to 1.5m (3 to 5ft), and a ramp available for loading.

Comparing flight characteristics, load limits, and dimensions of present and future cargo aircraft with the required characteristics of the ideal air

freighter, it can be seen that an aircraft similar to the Lockheed L-500 (civilian version of the C-5A "Galaxy"), one similar to the Boeing 747-200F, and an air freighter similar to the Lockheed L-100-50 "Hercules" stretch version are the acceptable aircraft for dedicated air cargo. The L-500 type and the B-747 type have similar payload and range characteristics. Choosing on the basis of intermodal suitability, it would appear that an aircraft similar to the L-500 is preferable because of the ease of loading. It is assumed that the defects in the current C-5A landing gear and wing will be corrected and the aircraft will be completely airworthy. The aircraft fleet for dedicated air cargo would consist of the L-500 type for long range and heavy loads, the L-100-50 for medium ranges and loads, and motor trucks and trailers for short range containerized cargo. Although this system concept does not include provisions for small individual packages, the regularly scheduled passenger carriers have ample capacity for belly cargo and will continue to transport small packages for some time to come.

1.5.4. Transfers Between Aircraft and Other Carriers

Standardized intermodal containers will facilitate the transfer of cargo between carriers. Standard containers in this study have been assumed and are described in Chapter 2 (ref. 39). They are the "M-1" containers measuring 2.44m x 2.44m x 3.05m (8ft x 8ft x 10ft) and the "M-2" container measuring 2.44m x 2.44m x 6.10m (8ft x 8ft x 20ft).

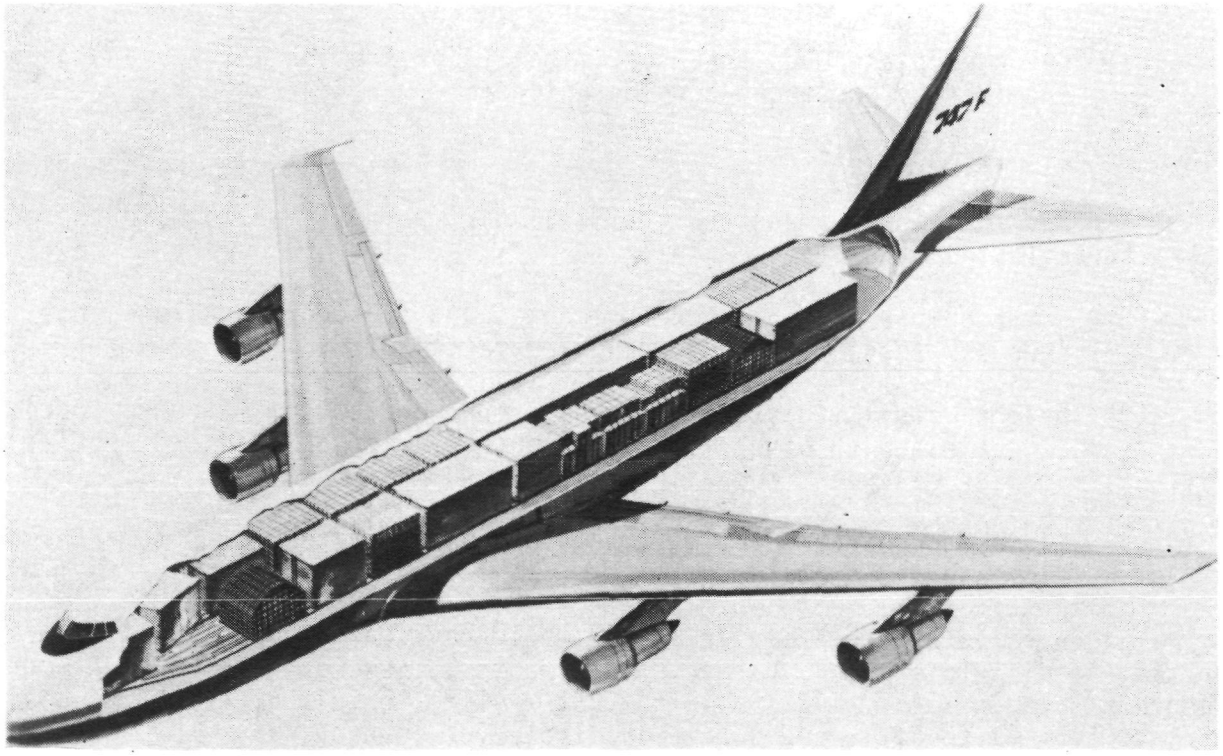


Figure 1.31 POSSIBLE AIR CARGO TYPES AND ARRANGEMENTS (Source: Courtesy Boeing Commercial Aircraft Co.).

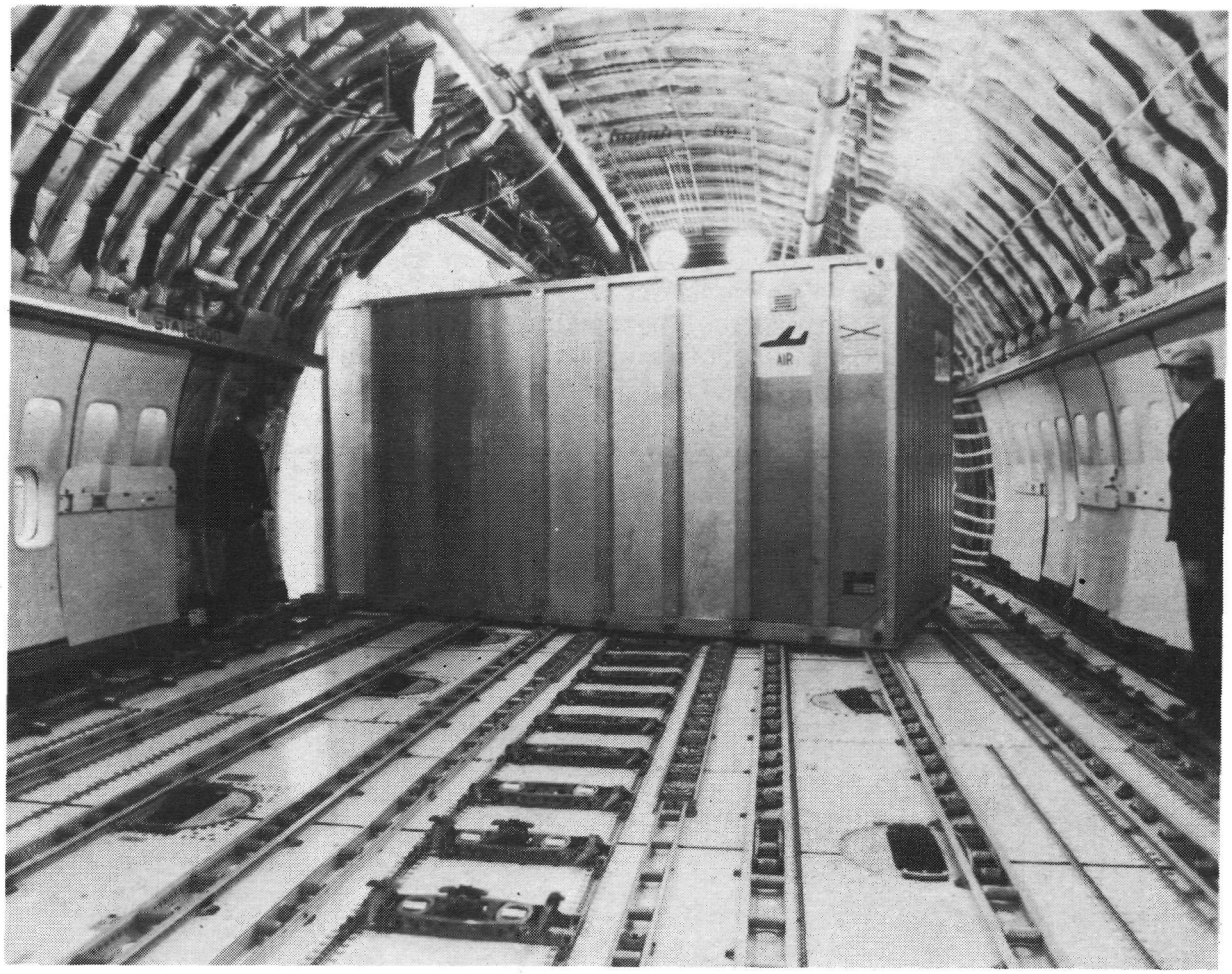


Figure 1.32 SIDE LOADING AN AIR FREIGHTER (Source: Courtesy Boeing Commercial Aircraft Co.).

Although this is the adopted standard, provisions ought to be made to utilize the 2.44m x 2.44m x 12.19m (8ft x 8ft x 40ft) container as well in order to optimize truck-trailer use and to expedite the transfer of trailer-load lots. The longest container, which is the actual trailer body, is the heart of ground transportation on roadway, rail; and water. Complete intermodal transfer of trailer-size loads already exists between truck-trailer, rail, and water carriers. Many other sizes and shapes of containers and pallets are available as well.

Figure 1.31 (courtesy of Boeing Commercial Airplane Company) shows a cutaway view of an air freighter fully loaded. Various sizes and shapes of containers, pallets, and other cargo are shown stowed in the aircraft. Included are three of the standard-size containers mentioned above. Not shown are "roll-on roll-off" type cargo such as trailers and motorized vehicles and equipment. Though not necessarily of standard size, this type of equipment is truly intermodal and must be considered in air cargo system design. This is especially true since the system design includes provision for transporting military cargo including motorized equipment

military cargo including motorized equipment. Ramp loading is essential in these cases for rapid and efficient loading and unloading. In the case of an entire load of fully motorized equipment, nose and ramp openings would allow simultaneous rapid loading and unloading.

Figure 1.32 (courtesy of Boeing Commercial Airplane Company) shows an M-2 container being loaded through the side door of an air freighter. On-board mechanized floor rollers shown here are designed to expedite loading with minimum use of outside equipment. The figure further illustrates the limitation of side door loading. The M-2 container shown is the largest that can be loaded in this fashion, and even it could be loaded much faster through a nose or tail opening. The figure further indicates that the opening shown is the smallest allowable since it can barely accommodate the standard container.

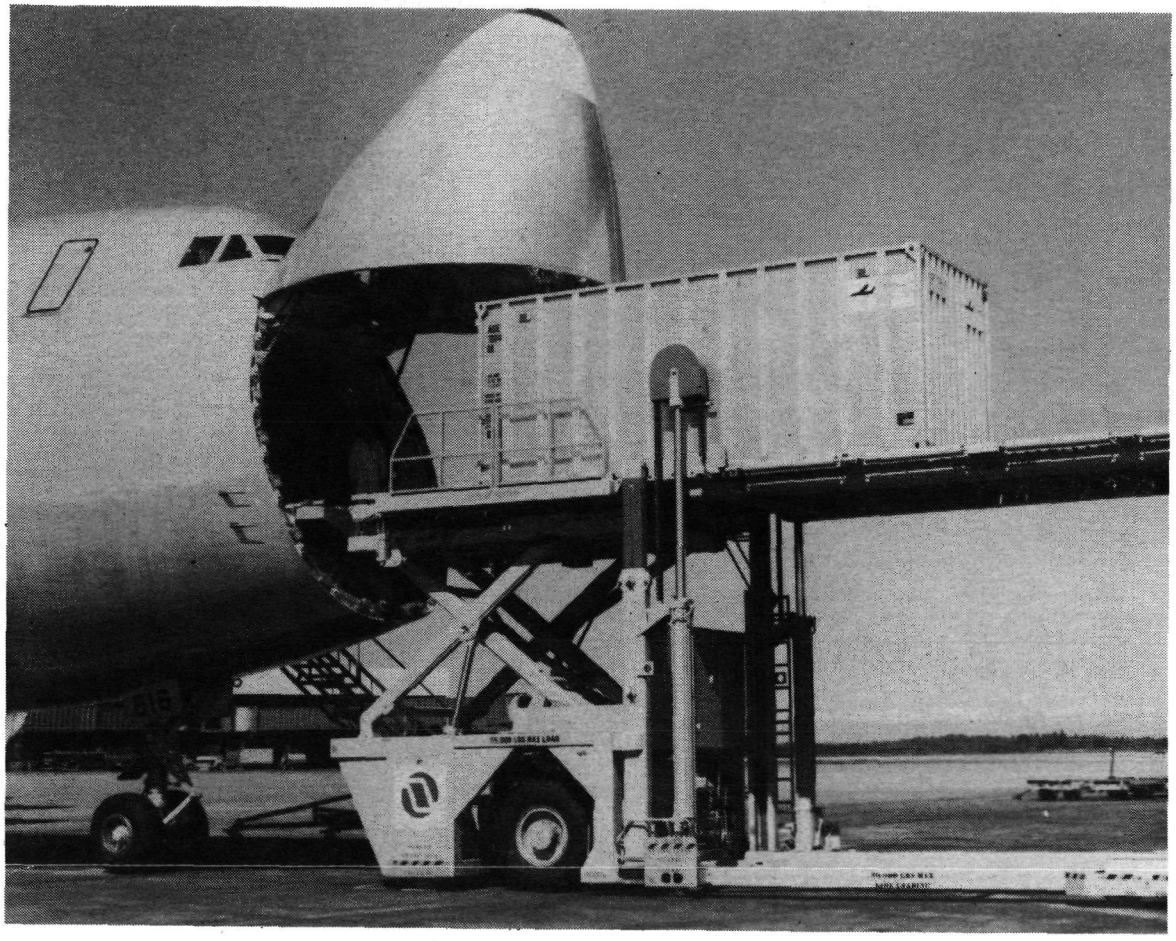


Figure 1.33 NOSE LOADING AN AIR FREIGHTER (Source: Courtesy Boeing Commercial Aircraft Co.).

Figure 1.33 (courtesy of Boeing Commercial Airplane Company) showing a nose-loading operation illustrates three salient features, two positive and one negative.

(1) An M-2 container is being nose loaded, indicating the relative ease and rapidity of this "straight-in" loading method. The 12.19m (40ft) trailer-size containers could be loaded just as easily in this manner. The Boeing Company's Air Freight Systems Office reports that the B-747's main deck can be fully loaded with containerized freight through the nose door in 25 minutes and through the side door in 30 minutes.

(2) The figure illustrates one type of loading equipment widely used and recommended for the typical situation in which ramps or platforms are either not available or at a height too low for the aircraft opening. This motorized transport loader can pick up the container at one location, transport it to the air freighter, elevate the load to sill height and, with its mechanized rollers, move the container into the aircraft opening. Many loaders of this type are available, such as the Kornylak Corporation high-lift "Karry All" scissors-lift truck. The same kind of equipment can just as readily load and unload trucks and trailers and, in fact, is ideal for loading intermodal containers between truck or trailer and aircraft.

(3) The figure illustrates the disadvantage of an air freighter whose opening is much higher than other modes of transportation. An aircraft with the recommended sill height of 1 to 1.5m (3 to 5ft) would allow for much faster loading and without the need of the expensive loading device shown.

Figure 1.34 shows container-loading operations at dockside, illustrating intermodal terminal transfer methods between rail, truck-trailer, and ship. These ideal facilities include provisions for loading rail cars, ships, and truck or trailer beds. In the foreground, a container is being loaded by a dockside crane with telescopic spreader. This spreader, similar to the one manufactured by A.S. Bromma Smides and Mek Verkstad of Stockholm, is electrically and hydraulically operated and can handle all sizes and types of containers.

In the left foreground of Figure 1.34 is shown the versatile straddle-container carrier that can load M-type containers up to 12.19m (40ft) in length from and to rail cars or trailer beds, can transport them to other locations, and can stack them three high. The type of straddle-container carriers suitable for the air cargo system are the Clark Company model 830L van carrier, the Valmet Oy of Helsinki "Valmet stacking straddle carrier," and the Mitsubishi, Tokyo, V-SC 4023 straddle carrier.

In the background of Figure 1.34 is shown the dockside rail-mounted container crane very useful for moving containers to and from ships and onto or off of cars, trailer beds, and warehouse platforms. Cranes suitable for use in intermodal transfer are those similar to the "Universe" multipurpose dockside container crane manufactured by Ishikawajima-Harema of Tokyo.

Figure 1.34 INTERMODAL TRANSFER EQUIPMENT FOR RAIL, TRUCK AND SHIP (Source: Courtesy Boeing Commercial Aircraft Co.).

All of this container-loading equipment is illustrated and described in Jane's Freight Containers (ref. 39).

The Project INTACT study (ref. 38) stressed two major underlying assumptions to characterize intermodal transfer:

(1) All freight entering or leaving the air cargo terminal will be by means of motor carrier.

(2) Cargo will be loaded into highway vans or intermodal containers at off-airport sites. These load devices will be driven to the airport and loaded aboard aircraft with a minimum of handling.

Optimum efficiency in intermodal transfer is obtained by loading containers, or even the trailer itself, aboard a C-5A type aircraft ramp or by using docks compatible with trailer-trucks and with the height of the sill of air freighters, facilitating rapid loading and unloading. Guide rails for wheeled vehicles and containers, container lift gantries, and self-contained, wheeled container-loading shuttles are devices illustrated in Project INTACT.

1.5.5. Off-Airport Consolidation

Intermodal transfer is based on the premise that all cargo to be transported by air freight is containerized. For some time to come, however, there will be shippers of less-than-container-size loads or shippers with container-sized loads of small packages who do not wish to bother with or do not have facilities for containerization. With more than half of air cargo tonnage consisting of small packages, some means for containering, sorting, and documenting them must be part of the intermodal transfer function.

The ideal cargo terminal or freightport should be divided into two or more areas (ref. 40) since the cost and scarcity of airport real estate directs the use of off-airport facilities for the receiving, storing, sorting, consolidating, and breaking down of freight units. Pallet and container loads would be trucked to the airport for flight consolidation, staging, and loading into freighters. Off-loaded containers simultaneously would be stripped from the aircraft and immediately dispatched to some remote handling and breakdown facility or truck distribution center. The off-airport parts of the terminal would consist of truck docks, a high-speed sorter capable of handling 6000 packages per hour, one igloo and container storage complex, one office complex, several automatic encoding stations and collating lanes, mechanized pallet build up devices, pallet and container stations, and outbound trailer loading docks. This portion of the terminal is essentially a transfer operation. Individual shipments are logged in and identified. It is desirable to have an "interrogable tag" by which the package could be machine sorted by type or by destination.

All storage is accomplished outside the building in semi-trailers. It is assumed that pallet breakdown and segregation is accomplished at a local delivery warehouse. Another invention necessary for this concept is a device to consolidate and breakdown random packages to and from container or pallet modules. A number of palletizers already on the market efficiently build uniform cartons into pallet loads. By combining the interrogable tag, a package size measuring machine, mechanical handling devices, and a computer, much more efficient cargo consolidation operations would be possible.

Michael L. Mastracci writing in the October 1968 edition of "Interavia" (ref. 40) described and illustrated an elementary air cargo distributions center. The center, designed, engineered, and installed by the American Machine and Foundry Company, turns around belly freight in 30 minutes. It utilizes the latest sorting and electronic devices to process 34 000kg (75 000lb) of mixed cargo per hour. It accommodates loose and palletized cargo and includes an electronic accounting system that weight-manifests cargo by flight and destination.

In general, intermodal transfer concerns not only the handling problem, but economics, the operational environment, personnel and time limitations, and all constraints. With the help of a few new developments, this ideal can be approached and a much more efficient cargo system realized.

1.6 AIRCRAFT MIX

1.6.1. Existing Aircraft and Derivatives

An air cargo system of greater capacity and efficiency obviously depends on the characteristics of the components which make it up. While designers can incorporate almost any features desirable in an aircraft, the time and capital investment involved in new design is such that any new aircraft must be assured of replacing a major portion of current ones in use to be economically justifiable. For the next few years, we must use designs that are already in production. In three to five years, derivatives of current models (wider, longer, taller, new doors, larger engines, etc.) could be available in quantity. New designs (ref. 41), once justified by demand, require several years for development, while features desired in a cargo aircraft but not compatible with the needs of passenger model raise the investment risk.

The following sections will present the candidates for cargo use among aircraft in use today and describe the features that are desirable or available for the various needs of an integrated cargo system of the immediate future.

1.6.2 Quick Change and Combi Concepts

In recent years, there has been an upsurge of interest in the air freight industry which is being served by (a) dedicated cargo aircraft, (b) the belly holds of passenger aircraft, (c) "combi" in which a wall is installed in the main deck so that a section of it is for cargo while the remainder is for passengers, and (d) QC (quick change) aircraft which can be converted quickly from an all-passenger to an all-cargo configuration and vice versa.

The aircraft offers the prospect of increasing utilization by extending the period of daily use. It can be employed as a freighter during the night when there is relatively little requirement for passenger operations and converted quickly to passenger use each morning. It also permits freight services to be offered in situations where demand is insufficient to utilize a freighter fully. However, some of the potential of QC aircraft has diminished in recent years as more airport authorities have imposed restrictions on night operations, particularly by jet aircraft. This poses problems for the air freight industry in general, but is particularly serious to the QC carrier. In addition, the greater risk of damage to the interior of the QC aircraft, coupled with the frequent complaints of residual odors, reduces its appeal for passenger use.

The combi appeals to some air carriers because of its ability to consolidate freight and passengers, now being carried by two smaller aircraft, into a single aircraft. An obvious example is the B-747 combi which is capable of accommodating pallets as well as standardized containers up to 6.10m (20ft) in length in the tail section while providing passenger services in the forward

section. Again, it is not as good as it seems. Freight and passengers have different flight schedules, passengers primarily during the daytime and freight primarily at night. In addition, passenger traffic often leads to the provision of separate terminal facilities located at different parts of the airport. Upon arrival at the passenger apron, freight vehicles would be hampered by, and add to, the congestion around the aircraft.

1.6.3. Desirable Aircraft Features

Until the introduction of wide-body jets into commercial use, there was little capability for moving the intermodal containers by air. The shape of the belly holds of aircraft and the door sizes did not permit large unitized loads, making freight handling slower and more expensive. Freight had to be handled as individual consignments placed in position manually and then secured with nets. This inefficient process of handling freight presents difficulty especially when turnaround times are short. The main deck cargo containers like the Igloos (Type A containers) used in the DC-8 and other aircraft provide an intermediate step, but the trend towards large consignments means some freight cannot be accommodated on narrow-body aircraft, and greater efficiency is needed.

Unlike narrow-body aircraft, the wide-body jets are capable of accommodating unitized loads in the lower holds and on the main deck if used as freighters. Due to the shape of the lower holds, the type of containers that utilize hold space most effectively are neither interchangeable with those of other aircraft nor compatible with other modes of transportation (a detailed discussion of containers will be given in Section 2.1.1.). The introduction of the intermodal container concept represents a positive step towards eventual standardization of all containers in the cargo industry.

With the increasing need for intermodal transfer of large containers, ground handling of large volumes of freight traffic will have to use the nose or tail for access to the aircraft. Nose and tail loading provides the fastest rate of handling since freight can be loaded and unloaded simultaneously. The C-5A is an example of this type of loading, and as a military freighter, it is equipped with a tail ramp to allow loading without ground equipment. Civilian freighters normally do not have a tail ramp as such flexibility can be achieved only at the expense of substantial reduction in payload. Nose or tail loading eliminates the need to rotate freight as it enters the aircraft as is usually required with side door loading. On aircraft with large payloads, the increase in handling time due to rotation will increase the turnaround time. Nose loading can be used only when the flight deck is positioned above the main hold, as in the B-747-200F, since pre-flight checkout must take place during loading for short ground times. The L-100-30 Hercules was designed with tail loading through a door just 104cm (41in) off the ground to allow unloading directly to a truckbed or the ground with little or no equipment.

Access to an aircraft often poses a problem in relation to its sill height above the ground. Most aircraft require lifting equipment to raise freight to the aircraft sill. For example, the sill height of B-747-200F is 4.9m (193in), L-100-30 Hercules is 1.0m (41in), and B-707 is 3.2m (125in).

The variation in sill height simply means that adjustable lifting equipment covering at least this range must be provided for different aircraft types at the airport terminals. The need for such ground equipment will result in additional handling costs. In the case of C-5A, the nose and tail can "kneel down" to facilitate loading directly from truckbed level. But such flexibility can't be accomplished in large aircraft without being a burden to the total aircraft cost. Thus, it is economically feasible for only the feeder aircraft to be designed with a cargo floor at the same level as the truckbed. This will obviate the need for lifting equipment at a large number of smaller airports.

The above discussion points out the advantages of (a) standardization of containers, (b) nose or tail loading, (c) compatibility with existing ground equipment, and possibly (d) aircraft sill at truck height, if it is aerodynamically and economically feasible. The future dedicated cargo aircraft should incorporate in its design all of these desirable features, in addition to defined performance characteristics.

1.6.4. Medium- and Long-Range Transport

Accurately predicting the future course of the air freight industry is at best precarious, as has been demonstrated by poor predictions in the past. In view of the uncertainty in the future and the subsequent "go slow" attitude among air freight carriers, it is not unreasonable to assume that the wide-body jets will remain in service during the next decade. The large-capacity, long-range aircraft, such as B-747-200F, will be handling the freight traffic between the hubs, and the medium-capacity aircraft, such as some of those listed in Table 1.6 (ref. 42) will serve the traffic between major and minor hubs or major city pairs. The B-747 design especially appears to have flexibility for derivative growth. The B-747-200F and its stretched version will most likely continue to provide services in the 1990's, though there will be requirements for smaller freighters. As in the past, these short/medium-range freighters probably will be derived from then existing passenger aircraft.

As the advantages of containerization become more widely accepted by the shipping community, a larger share of the freight will be unitized in larger containers. Consequently, the narrow-body jets would gradually be phased out of the prime markets and replaced by more efficient freighters capable of carrying loads in the large containers. A new generation of smaller cargo aircraft may also result as the demand justifies them.

The consensus seems to be that by 1990 there will be a dedicated freighter equipped with quieter, more efficient engines capable of carrying at least 100tonnes (200 000lb) payload over 6500km (4000mi) range. It will be nose or tail loading with a main deck which will accommodate intermodal containers up to 12.2m (40ft) long. The lower holds will accommodate contoured containers. For the medium range, there will be a freighter with quieter, more efficient engines which will carry a payload of 36 000kg (80 000lb) over a range of 2400km (1500mi). Loading will be through a tail or nose door, approximately 3m (10ft) wide by 2.7m (9ft) high to accommodate standardized intermodal containers. Payload and range are chosen in accordance with the hub-spoke concepts discussed earlier.

Table 1.6

Aircraft Type	Payload 1 tonnes (lb)	Range km (mi)	Cargo Handling	Noise Level (EPNdB) Takeoff	Approach	Sideline
B-747-200F	113 (250,000)	5300 (3300)	Nose loading Accepts M type containers to 12 m length Side cargo door optional	107	106	98
L-100-30 * Hercules	23.1 max. (51,000)	3400 (2100)	Tail loading Accepts M type containers to 12 m length	98.4	99.1	93.9
A-300-B4FC (European Airbus)	37.2 max. (82,000)	4200 (2600)	Side loading Accepts M-1 containers	92	101	95
L-1011-500	44.5 max. (98,000)	9800 max. (6100)	Side loading Accepts LD-3 containers	97	103	95
DC-10-30CF	70.6 max. (155,700)	4800 (3000)	Side loading Accepts M-1 containers	104.4	109.0 (50^{o} approach)	99.7

* There is a proposed 'stretched' version, with 35' longer fuselage, designated as L-100-50.

1.6.5. Limited Role of Crane Helicopter (ref. 43)

A special NASA/Army/Navy committee examining a renewed interest in the heavy-lift helicopter has said that a heavy-lift civil helicopter derived from a military version could fill "civil needs in construction, logging, energy resources development, and cargo container distribution" (ref. 44). This statement is in line with the view that a crane helicopter could be used, on a selective basis, specifically for moving containerized cargo to and from congested cities within a radius of, say, 160km (100mi) from the terminal area. The helicopter has the inherent advantage of being immune to surface delays and it can fly over lakes, canals, and industrial areas rather than having to go around them. It thus can be operated with a high degree of schedule reliability. In addition, it is capable of serving any area without the necessity of large and expensive landing facilities and it operates below most regular air lanes. It can accommodate any truck-load size container so long as the loads are within its weight limitation. The configuration of the helicopter makes it ideal for rapid loading and unloading and will provide a unique interfacing unit if it proves economically feasible.

Air shipment is a comparatively expensive but superior form of transportation of goods. Its future growth will depend on the shipper's willingness to pay for the high transportation cost in return for short transit time. The latter allows a reduction in inventory and warehouse costs, lowers the danger of damage to goods in transit, and provides the opportunity for faster response to changing market environments. The future growth will be stimulated when the air freight industry is able to provide guaranteed overnight or even second day service between any two domestic cities. The crane helicopter has the speed capability necessary to make an overnight system operational in certain physically isolated or congested areas.

The crane helicopter being considered may be similar to the Sikorsky S-64F Skycrane (ref. 42), capable of picking up one or more standardized intermodal containers by means of the dual rails on the underside of the body. The containers, loaded at the terminal, could be moved by forklift or conveyor to the loading dock and loaded directly under the helicopter. Large shippers, and possibly air-freight forwarders, may load the containers themselves, in which case the containers can be picked up from their loading platform with a minimum of ground handling.

Upon arrival at the destination city or freightport, the containers can be released directly onto a flatbed truck for direct trucking to the consignees within the local delivery zone. In the case of a large shipper, the container will be deposited directly on the firm's loading platform.

"Reorganized and revitalized U.S. rotary-wing research effort is entering an intensive phase marked by the advent of advanced flight and ground-based facilities that will help provide this nation's helicopter operators with much-needed new technology." (ref. 45) Against a background of imminent advances in rotary-wing technology, coupled with the further deterioration and congestion of highways in the vicinity of possibly saturated airports in the 1990's, it is reasonable to assume that the future crane helicopter will be

more competitive with the truck and will play a more viable role in the air freight industry. Despite the well-publicized problems associated with high operating costs and noise level, it is believed that the limited role of crane helicopter in the short haul transportation should be explored. This will present a great challenge to current helicopter researchers and manufacturers to come up with a truly fuel-efficient and low-noise crane helicopter in the future. The other aircraft required to make the integrated air cargo system function already exist, though modifications are desirable and new designs will follow inevitably as demand dictates.

1.7 IMPACTS

1.7.1. Introduction

The purpose of this section is to establish the extent of the benefits or disbenefits which are likely to accrue from the actual implementation of a dedicated air freight system. In particular, the emphasis is upon the deleterious or undesirable affects which are likely to result, since an understanding of these impacts will improve management of the development and implementation of the advanced air cargo system. It is noted that a previous report (ref. 3) has already been produced on this subject.

This discussion is concerned only with those impacts which the air cargo system has upon the larger societal-ecological system in which it is embedded. The focus here is largely upon the network routes, schedules, aircraft choices, and fleet size. In later sections, the impacts of other components of the air cargo system will be treated.

1.7.2. Physical Impacts

Network design weighs rather substantially upon the fuel consumption requirements of the total air cargo system. A low connectivity hub-spoke network means the cargo must be transported over more kilometers, but larger aircraft requiring less fuel per tonne-kilometer of transportation will be used.

In addition, the Gellman report (ref. 3) suggests that large cargo aircraft might be used to transport minerals and ores. If this happens, it would result in lower in-transit inventories of these goods, in quicker response times to changes in market demand, and in shifts in domestic employment. There has been no indication that large cargo aircraft would be used to transport raw fuel resources such as coal, oil, or gas. As a partial solution to the backhaul problem, refs. 31 and 49 suggest only that refined minerals will become eligible backhaul cargo for select regions.

Network routes will roughly parallel those in existence today. These corridors will sustain higher traffic densities in the next 25 years without measurable impact.

Dedicated air cargo flights can be scheduled around existing passenger arrival and departure peak densities, thereby necessitating few additional airport runways. It is anticipated that such scheduling will not degrade service to the shipper or to the passenger.

Choice of dedicated freight aircraft to be deployed will have important impacts upon the associated airframe and engine manufacturers as will the fleet sizes and mix. At this time, it is difficult to determine whether

existing airframe manufacturing facilities will be able to handle the required production rate of the dedicated freight aircraft without expansion.

1.7.3. Environmental Impacts

The environmental impacts of new air freightport construction and existing airport expansion are discussed elsewhere (see Section 2.7.2.). Treated here are the impacts of the links of the network rather than the impacts of the nodes, for the reasons cited previously. The links or routes of the network determine where the aircraft will be flying. For the population located beneath these links there will be some slight environmental degradation in the form of vapor trails and noise. Fortunately, major international hub-to-hub routes are over water.

The development and use of new aircraft engines which are more energy efficient and quieter should allow routes over heavy population centers provided the aircraft is 2000m (6500ft) or more above the ground. These engines may permit night-time arrivals and departures into some airports.

The effects of the air cargo system upon air and water pollution are considered tolerable and in most cases preferable to the resultant air and water pollution accruing from transportation of the same cargo by surface modes. Solid-waste pollution by the air cargo system is considered negligible (see Section 2.7.2.2.).

The impacts of the air cargo system upon land use are considered elsewhere (see Section 2.7.2.2. and 2.7.2.4.).

1.7.4. Societal or Cultural Impacts

As the air cargo system grows and becomes more profitable, it is anticipated that organized labor will become more adamant and insistent upon its own terms. This poses the possibility for international labor organizations with extraordinary power -- enough to prevent an entire country from getting the food supplies it needs. Since this fleet of dedicated cargo aircraft could be used to airlift emergency medical supplies to disaster areas, to airlift much-needed weapons, foods, fiber, or precious minerals, an international labor organization which could stifle such operations might become a considerable political entity.

Second, the immensity of this system also gives rise to the possibility of increased international crime. The hijacking of a single freighter could have international implications. There may also be increased opportunities for smuggling (of drugs, for example).

Mechanization, inherent in containerization, raises the skill levels of the required employees at the same time it reduces their numbers. The current practice among leading air cargo firms seems to be to hire the best qualified people available for "unskilled" jobs such as local truck drivers in order to maintain versatility and judgement on all levels. As competition increases, the pressures to economize by hiring less competent employees could jeopardize

the system through inefficiencies and increased mishandling.

Finally, it would be possible for a country to launch a surprise attack on another country by airlifting a large number of weapons and soldiers into the country under the guise of air cargo carriers (the old Trojan horse trick).

Thus it must be reckoned that although this technology carries with it considerable opportunity to benefit society, it also increases the possibility for massive abuse.

The impacts of an air cargo system upon such other societal factors as international politics, foreign policy, domestic growth, employment, international trade, imports, exports, jobs, quality of life, distribution of wealth, health, new business, population migration, lower freight rates, and marketed goods are considered later in this report.

1.8 SUMMARY AND CONCLUSIONS

Following is a list of conclusions emanating from the network studies described in this chapter.

1.8.1. Conclusions Related to Connectivity, Routing, and Hub Location

1. A hub-spoke infrastructure should be used for movement of the cargo. This concept applies both to surface transport links and to air transport links. Thus trucks move the cargo to its first consolidation point -- the hub or feeder freightport -- and deliver it to its final destination. A hub-spoke arrangement lowers the connectivity of the network and increases the frequency of service for a fixed capital investment in aircraft.

2. Superimposed upon the pure hub-spoke network are numerous direct routes between city pairs over which heavy volume is transported -- enough to permit 50% of the total volume to be transported by direct routes.

3. Three large, efficient freightports should be developed in the vicinity of San Francisco, Houston, and New York. These dedicated freightports will serve as international hubs or "gateways" for movement of both domestic and international freight.

4. Central place theory may usefully serve in locating hubs and spokes for the network. The hierarchy of hexagonal areas provides for service to all areas, from the smallest and least efficient units to large continents utilizing efficiency of scale. No pure network organization will do justice to all special cases that have developed historically; there simply is not enough flexibility in any single system or concept.

5. An organized gathering of information on existing civilian and selected military airports should be undertaken so that rational decisions can be made on expansion potential in accommodating the larger freightports and consolidation facilities needed for hub and feeder portions of the system and for locating new intermodal nodes in which air cargo may or may not be the initiating force.

6. The economics of an advanced air cargo system should be studied from the point of view of its infrastructure; that is, compatible network, scheduling, and fleet sizing designs should be developed, and from these designs, the economics of the system can be outlined more comprehensively. This is the approach that is employed by the air passenger carriers.

7. Statistics and ranking of airports for cargo should be based on the larger of the enplaned or deplaned cargo moved. This is a more equitable base across airports since, unlike passenger traffic, cargo flows are often strongly unbalanced. This base would retain the peak handling nature of the airport's

cargo operation, though total volume would still determine the ranking for revenue purposes.

1.8.2. Conclusions Related to Aircraft

1. The use of extraordinarily large aircraft may, in spite of their economies of scale, have important routing and scheduling disadvantages. In particular, they:

A. lessen the frequency of flights, thereby
   1. lessening demand which is sensitive to frequency of service,
   2. lessening the number of connecting flights,
   3. increasing the delays at the nodes of the network, and
   4. increasing the terminal storage required at each node.

B. lessen the number of direct flights, thereby increasing the amount of consolidation and breakbulk handling required,

C. increase the number of kilometers (miles) over which the freight must be carried,

D. increase the length of time required to deliver the freight.

2. Aircraft which are too small also have decided disadvantages for routing and scheduling. In particular, they dictate highly connected networks over which many more aircraft are required in order to achieve reasonable frequency of service because of the larger number of routes.

3. Large cargo aircraft (such as the 747-200F, the 747-11/11F, L-500) appear especially appealing because developmental costs have already been largely amortized by previous sales of the aircraft, thereby lowering the price which the airframe manufacturer must charge.

4. The combined and quick-change aircraft concepts have particular appeal from a scheduling point of view. Their increased flexibility should permit greater utilization of the aircraft and should facilitate solution of backhaul and related scheduling problems.

5. Research activity should be directed toward the development of quiet, fuel efficient engines which could be retrofitted into existing large cargo aircraft.

6. The future dedicated air freighter should, if aerodynamically and economically feasible, incorporate in its design such features as (a) nose or tail loading, (b) compatibility with existing ground handling equipment, (c) compatibility with other modes of transportation, and possibly (d) aircraft sill at truckbed height.

7. Despite the well-publicized problems associated with high operating costs and noise level, it is believed that the limited role of the crane helicopter in the short haul transportation should be explored. This presents

a great challenge to current helicopter researchers and manufacturers to come up with a truly economical, fuel efficient, and low-noise crane helicopter in the future.

8. A more formal study of air cargo density may be required to insure that future aircraft designs are aimed at the optimal volume and lift combination. Few of today's air cargo loads tax the lift capability when the volume is filled, but the increased demand for air transport may or may not result in significantly greater average densities of air cargo.

1.8.3. Conclusions Related to Scheduling

1. Through appropriate scheduling, it should be possible to blend additional dedicated air freight movements with passenger movements, in those airports where both passengers and freight are both being accommodated, without necessitating additional airport runway expansion before 1990.

2. A computerized reservation system for movement of cargo over all modes should be developed and implemented. This would be highly compatible with the independent commission agent concept to be discussed later (Chapter 3).

3. The use of demand-sensitive dynamic scheduling, as would be particularly compatible with a computerized reservation system, may serve to increase load factors substantially with no degradation of service. Such a technique might serve to reduce the problem of backhaul and would certainly contribute to increased profits.

4. Even though air freight shippers want their cargo moved at night, at least some of the cargo (35%) will have to be moved during the day to enable the air freight carrier to obtain adequate aircraft utilization, unless these aircraft can be converted almost daily for use as passenger carriers.

5. Because of the dimensionality of the scheduling and routing problems, algorithms to assist planners in such activities are more likely to be heuristic than optimizing.

1.8.4. Conclusions Related to Facilities and Operations Design at the Nodes

Delays in the system occur at the nodes, therefore the nodes warrant special attention. Containerized cargo handling at the nodes is a key to speeding up loading and unloading. Further progress in standardization of containers is indicated.

1. Alternative containerizing, loading, and storage designs should be explored to insure maximal utility of investment over the next decade in which radical changes in the air cargo industry will probably occur. For example, an aircraft elevator may be preferable to an adjustable loader for the high B-747 and the lower L-500 which may become available and offer several advantages. For some time, both aircraft may have to be accommodated, and facilities built for one may be inefficient or useless for a mix of the two.

2. Past and current automated techniques should be cataloged and analyzed in order to determine where the successes and failures have occurred in past profit-making operations. The tendency to assign all functions to machines, even where the human operator is more efficient, must be avoided. Long-term reliability and versatility may be more important than short-term handling capacity.

1.8.5. General Conclusions

The mechanisms by which a significantly different, rational air cargo system could be brought about merits further study. Clearly interfirm, intermodal coordination is needed for deriving a single cargo organization at each airport, but the various competing agencies must somehow be brought under one evolving hierarchy, probably a trade association, in order to derive the benefits a single system promises. In the process, the incentives of free enterprise must be retained.

The trade-off between cost and time must constantly be remembered. Though the mathematics of the problem may indicate one solution, the value placed on time by the user of the system must not be forgotten.

A theoretical model of a network may be suitable for initial studies; but the analysis of a specific network of routes and terminals will yield more reliable data.

To simplify the economic analysis of a complex air cargo system, it may be necessary to optimize each phase of the network.

If the railway network in this country is revitalized, its effect on the proposed air cargo system could be substantial. The truck link and, in particular, the feeder aircraft link could be replaced by a rail link if that revitalized system is rapid, reliable, and economical.

Advances in helicopter fuel efficiency and in range could certainly make this mode of transportation more attractive for the pick-up and distribution of containerized cargo. This would decrease the use of trucks for the first and last links of the cargo movement.

No matter how sophisticated, any model which uses the forecasts of future situations is susceptable to error. Major and occasionally minor errors in estimating future demands, capabilities, and operations could negate the conclusions of an economic analysis. As a result, it is not unusual to find that "gut feelings" may give useful indications of trends just as accurately as a complex computer simulation.

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